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THE NEURAL CENTERS CONCERNED IN THE MEDIATION OF APPARENT MOVEMENT VISION

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Since Wertheimer (**13**) first defined the problem of apparent or stroboscopic visual movement, the neurological or physiological basis for this perceptual process has been the subject of frequent conjecture but of no direct experimental investigation. In his 1912 article, Wertheimer proposed that apparent movement vision might be explained on the basis of short-circuiting neural currents in the higher centers of the nervous system. Köhler (**4**) discounts the theory of short-circuiting, and insists that apparent movement is phenomenally present because of the dynamic interaction and union of the discrete excitatory processes 'below the psychophysical level.' It is not clear whether the 'psychophysical level' refers to the cortex or whether such anatomical considerations are of no importance. At any rate, apparent movement occurs only if the interaction takes place below the psychophysical level, for at this level, only one process is present, which is displaced from one point to another to correspond to the seen movement. DeSilva (**2**) feels that the Gestalt theories have ignored or minimized the unquestionable influence of subjective determination, and proposes to adopt Henry Head's theory of 'schematism' to account for the central determination of apparent movement vision. Piéron (**5**) also emphasizes the rôle of the subject's attitude, and states further

that the mechanism of the conditioned reflex accounts for the appearance of apparent movement vision.

The futility of pure theorizing may be avoided to some extent by direct investigation of the phenomena of apparent movement vision in animal subjects. With physiological and surgical techniques available, it is possible to investigate such problems as the following: (1) What similarities and differences exist between the neural determination of real and of apparent movement in vision? (2) What is the relative importance of cortical and of subcortical centers in the mediation of such perceptual processes?

In the present experiment, the responses of guinea pigs to apparent movement stimulation have been investigated following bilateral removal of the occipital areas of the cortex, unilateral decortication combined with removal of the occipital area of the other hemisphere, and complete bilateral decortication.

A. Apparatus

The method employed in the following experiments involves the observation of the head nystagmus which is produced in guinea pigs by stroboscopic movement of a striated pattern across the visual field.[1] This general method of investigation of visual functions in mammals has been described previously in connection with experiments on visual acuity, movement discrimination, and pattern vision in cats (**7**, **9**, **11**, **12**).

The apparatus used consists of a rotating drum which presents a striated pattern made up of alternate black and white lines of equal width, a stroboscope which provides intermittent illumination of the stripes of the drum, and a recording system for registering the head nystagmus of the guinea pig. In Fig. 1 is shown the arrangement of the apparatus. This diagram does not represent the striations of the drum but merely its relative size and form.

The rotating drum has previously been described in detail (**10**, **11**). It suffices to repeat here that the striated pattern of the drum is provided by fifty white cardboard strips, so cut and mounted on the supporting ribs that the width of the strips in any horizontal plane is equal to the width of the interspaces. Since the walls of the experimental room are painted black and the light source is located within the drum, the interspaces form black striations of high contrast to the white cardboard strips. The direction and speed of rotation of the drum are controlled by appropriate switches and calibrated slide resistances.

[1] Hereafter, the terms 'stroboscopic movement' and 'stroboscopic presentation' will be used to refer to the nature of the stimulation used in the experiment, *i.e.*, the presentation of a discrete stationary pattern at different positions at successive points in time. The term 'apparent movement' will refer to the response of the animal to such stroboscopic patterns.

The Edgerton stroboscope [2] has been used as a source of intermittent illumination in these experiments. This apparatus, which consists of a mercury vapor lamp, a power supply, and a synchronous motor contactor, is arranged as shown in Fig. 1. The mercury vapor lamp is supported by a rod and placed directly above the guinea pig's head within the drum.

The nystagmic head movements of the animal are recorded on an ink-writing polygraph located on a table near the drum. The animal itself is put in a small box-holder which leaves the head free for movement. It is then placed on a small platform attached to a rod-support approximately at the center of the drum. A light silk thread attached to the animal's nose is led through glass guides and connected to a light ink-writing lever on the polygraph.

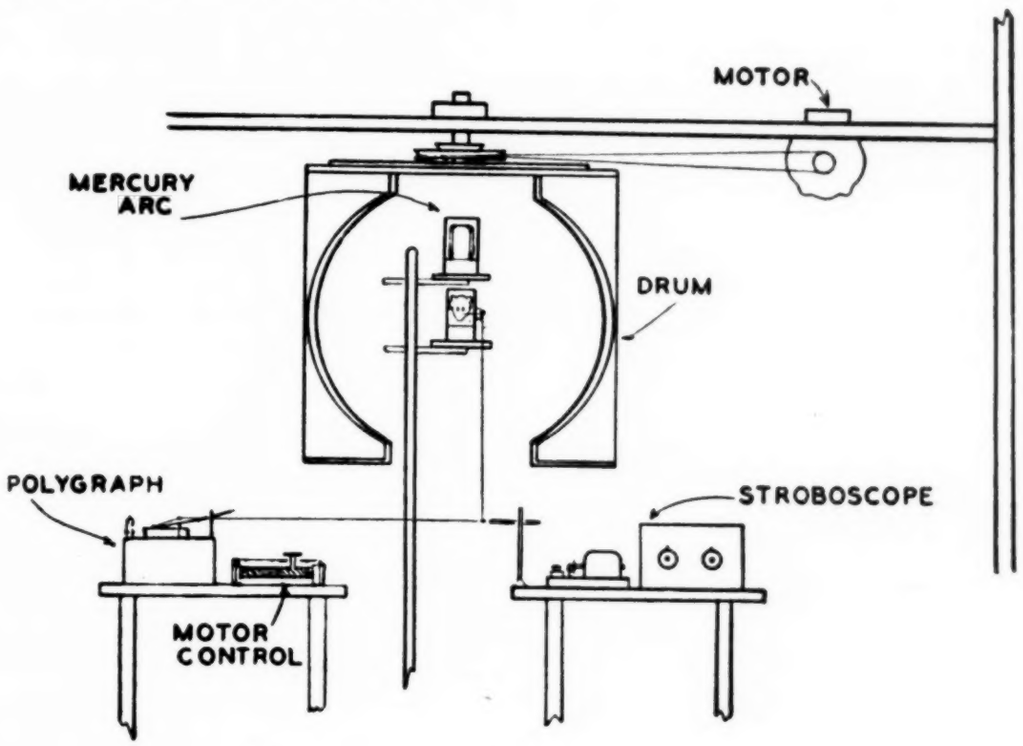


FIG. 1. Diagram of the apparatus. The striations of the drum are not represented in the diagram.

B. PROCEDURE

Throughout the experiments reported here, the drum was rotated at a constant velocity, 108 degrees per second. Varying velocities of stroboscopic movement were produced by changing the flashing frequency of the mercury vapor lamp. The frequency of the stroboscope was always adjusted to a value greater than that of fundamental synchronism with the velocity of the stripes, so that the stroboscopic displacement of the stripes was always in a direction opposite their real movement. Reversals in the direction of the stroboscopic movement were made by reversing the direction of the real rotation of the drum. The speed of the stroboscopic movement could be estimated in two ways, by computation from drum speed and stroboscopic frequency, and by direct observation and timing by the experimenter.

[2] General Radio Company, Cambridge, Mass.

When testing an animal, the polygraph was first made ready for recording and the motor control of the drum adjusted to give a velocity of 108 degrees per second toward the left. The motor contactor of the stroboscope was then set at a flashing frequency which would provide a slow stroboscopic movement of the stripes toward the right at a velocity of approximately twelve degrees per second. All of the lights of the experimental room were then turned off and the polygraph started. After approximately thirty seconds, the mercury vapor lamp was turned on and allowed to flash at the adjusted frequency for two or three minutes, after which it was turned off. The polygraph was kept running for approximately thirty seconds after the light was turned off. Thus, a record of the animal's activity was secured before and after as well as during the stimulation period. The record also included a time line in seconds, and a stimulus line indicating the onset and termination of the stroboscope light.

After a short rest period, the direction of the rotation of the drum was reversed so that the stroboscopic movement now occurred toward the left, and the test was repeated. Further records were secured with stroboscopic movement to the right and to the left at velocities of 18 and 36 degrees per second. It should be noted again that in all of these observations, the drum speed remained constant and the variations in the velocity of stroboscopic movement were produced by altering the flashing frequency of the mercury vapor lamp.

Control observations were made on each of the animals by setting the flashing frequency of the stroboscope to fundamental synchronism with the velocity of the stripes. Under such conditions, the stripes of the drum appear not to move.

C. Animals and Operations

Of the eighteen guinea pigs employed in the experiment, thirteen were given both preoperative and postoperative tests, and five were tested only postoperatively. Nine of the first group were tested at all three velocities of stroboscopic movement in the preoperative as well as in all of the postoperative observations.

TABLE 1

The Sequence of Operations and Order of Tests Given Each Subject

Subject	Normal	Occ. Areas	Right Cortex	Left Cortex	One Cortex and Occ. A.	Decort.
102	1		2			3
103	1					2
104	1					2
105						1
106			1			2
107	1		2			3
108	1			2		3
109	1		2			3
110				1		2
111			1			2
112	1	2			3	4
113	1	2			3	4
115		1			2	
116	1	2				
117	1		2		3	
118	1			2		
119	1	2				
120	1	2				

Table 1 indicates the types of operation given each of the animals and the order of tests given under each condition. For example, Subject 102 was observed preoperatively, tested again after removal of the right cortex, and a third time after complete bilateral decortication.

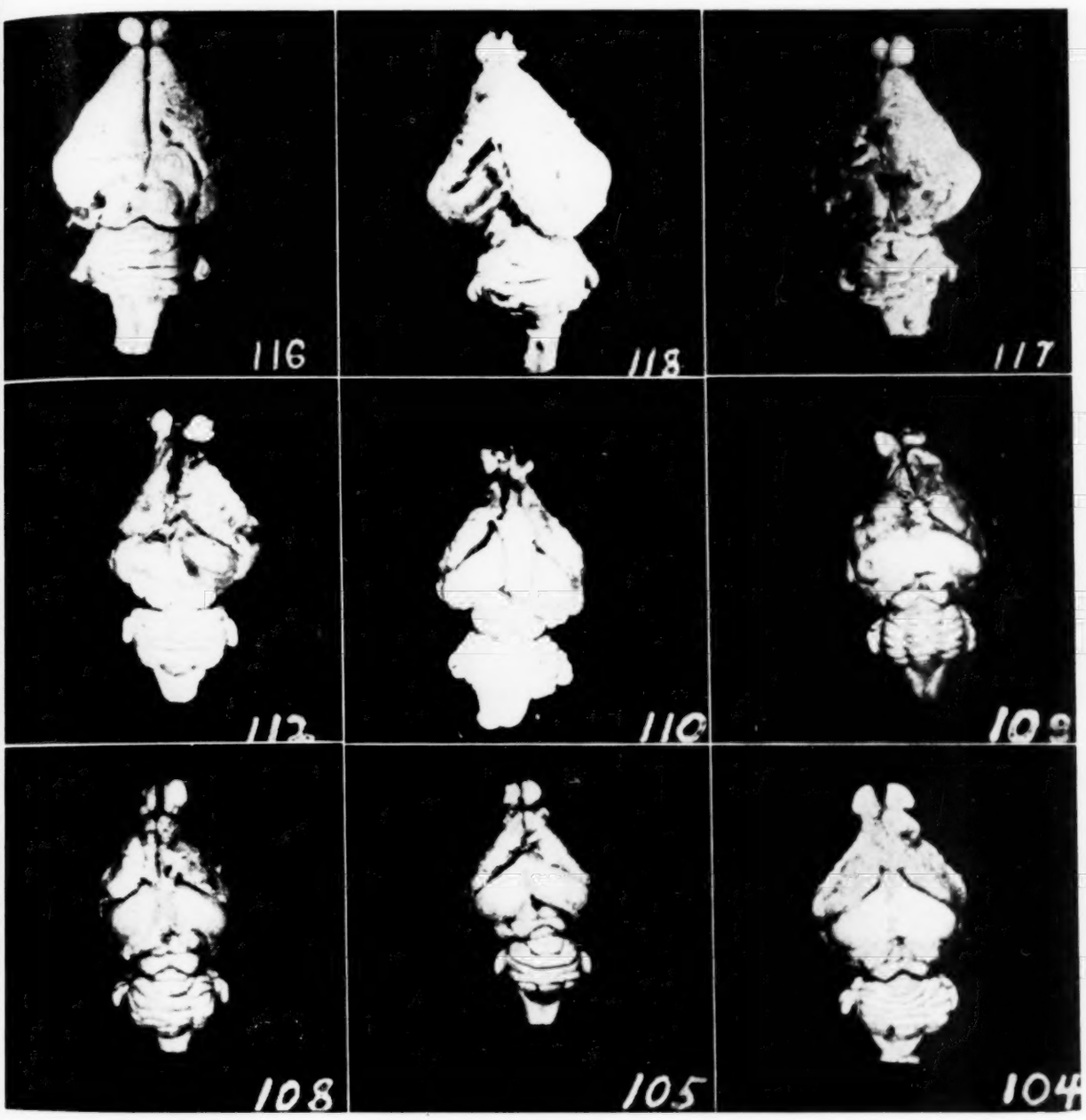


FIG. 2. Photographs of the brains of nine subjects. Subject 116—Removal of occipital area. Subject 118—Hemidecortication (L). Subject 117—Hemidecortication (L) combined with removal of the right occipital area. Subjects 104, 105, 108, 109, 110, 112—Bilateral decortication.

In Fig. 2 are shown photographs of the brains of nine of the operated animals used in the experiment. The brains numbered from 104 to 112 are those of decorticate animals, while the three brains at the top of the plate represent respectively the removal of the occipital areas (119), the left cortex (118), and the left cortex and right

occipital area (117). Examination of the brains of the decorticate animals will show that in Subjects 104, 109, and 112, small bits of cortex remained intact frontally or temporally.

The operations on these animals were carried out aseptically under Nembutal anæsthesia. A midline incision was made in the scalp, and the skull under the temporal muscle was cut away with a small electric burr and bone forceps. The cortical tissue itself was removed by means of a small pipette attached to a suction pump, a method which permits precise destruction of any desired region of the cortex without injury to subcortical structures. After an animal was tested it was killed and perfused with 5 percent formalin through the aorta. The brain was later removed from the skull and photographed.

D. Results

In order to describe more clearly the conditions of stimulation, Table 2 is introduced here prior to a discussion of the

TABLE 2

Conditions of the Stimulus Complex at Three Speeds of Stroboscopic Movement

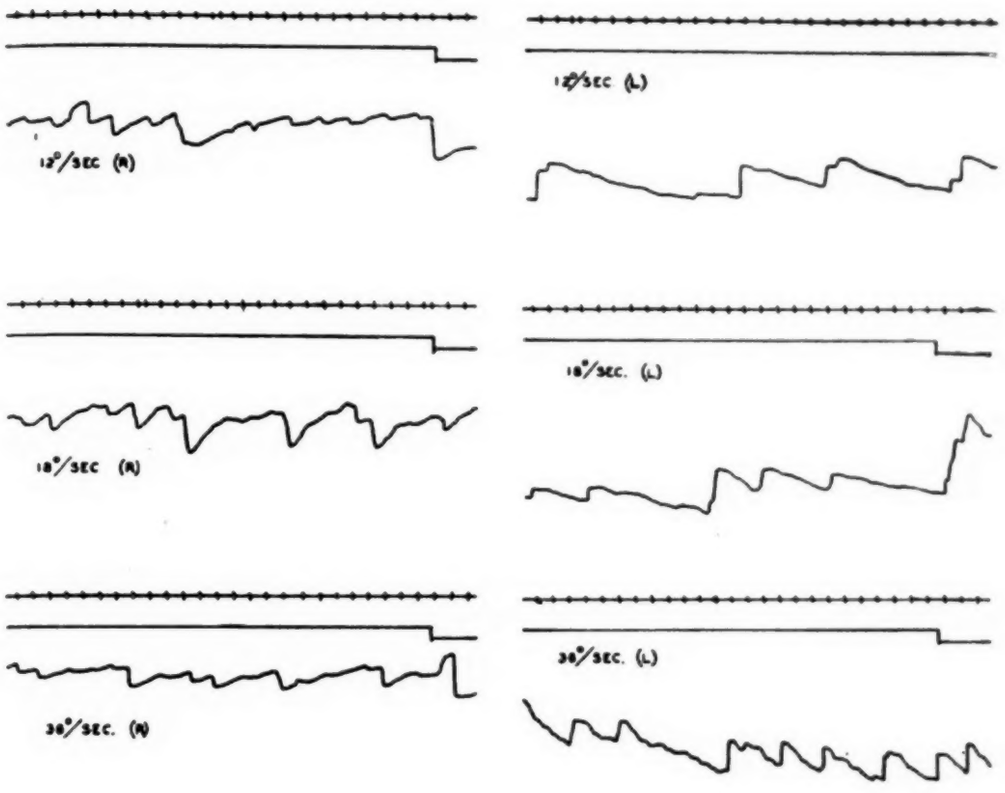
Drum Speed (Stripes/Sec.)	Stroboscope Frequency (Flashes/Sec.)	Stroboscopic Movement (Stripes/Sec.)	Stroboscopic Movement (Degrees/Sec.)	Stroboscopic Separation (Degrees)
15	16.7	1.7	12	0.7
15	17.5	2.5	18	1.0
15	20.0	5.0	36	1.8

records obtained. In this table, the first two columns give the speed of real movement of the drum in stripes per second and the frequency of the stroboscope in flashes per second. The difference between these two values gives the velocity of stroboscopic movement in stripes per second (Column 3). This latter value is also converted into degrees per second. The last column gives the stroboscopic separation in degrees, that is, the degree of separation of two successive stationary[3] patterns which are seen as an apparently moving stripe.

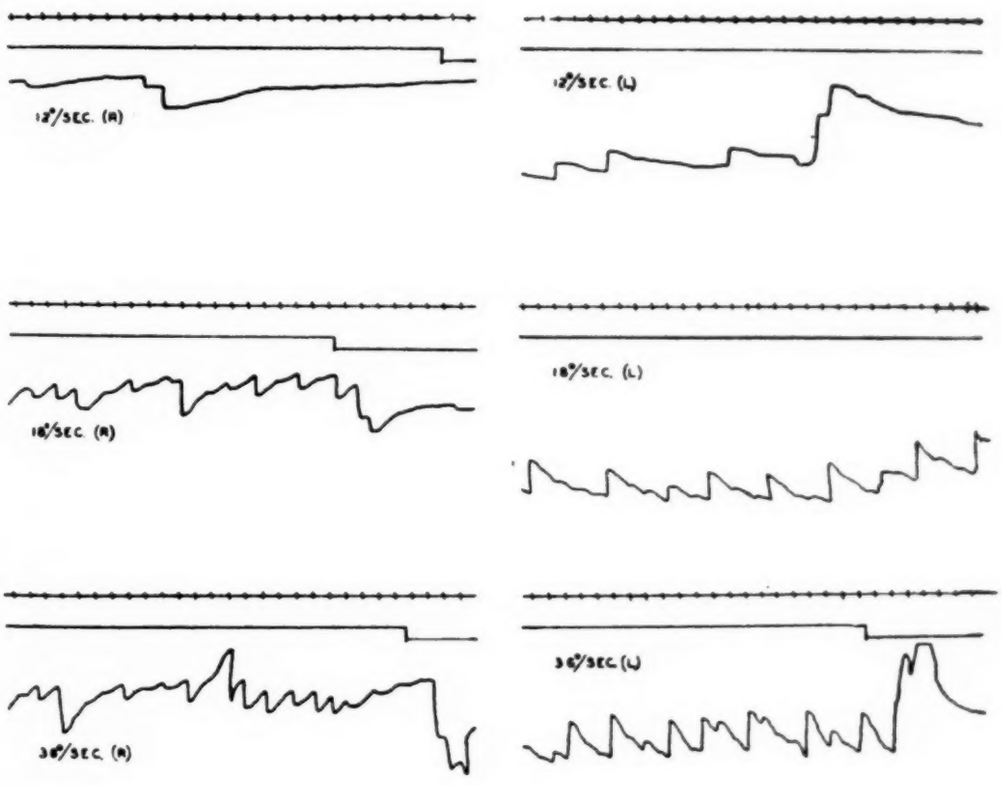
1. *Responses to Stroboscopic Movement Stimulation in Normal Guinea Pigs*

In Fig. 3 are shown records secured from normal guinea pigs when stimulated by the three different speeds of stroboscopic movement used in the experiment. The records pre-

[3] The stimulus patterns may be regarded as 'stationary' since a single flash of the Edgerton stroboscope has a duration of only 5–10 microseconds.



PIG 104 NORMAL



PIG 109 NORMAL

FIG. 3. Head nystagmus produced by stroboscopic movement in two normal animals.

sented in this figure are photographic reproductions of retouched polygraph records. The top line of each record indicates time in seconds, the second line is the stimulus line, and the third is the record of the head movements of the guinea pig. An upward deflection of the stimulus line indicates the onset of the light stimulation, and a downward deflection, the termination. In the nystagmus record, an upward deflection corresponds to a movement to the right, a downward deflection, a movement to the left. The records at the left of the figure were obtained with the stroboscopic movement toward the right, those at the right of the figure with the movement toward the left.

Examination of the records will show that stroboscopic movement of striated visual patterns elicits in the guinea pig consistent orientations correlated with the direction of the stroboscopic movement. When the stroboscopic patterns are moving toward the right, the head responses of the animal consist of two phases, a slow pursuit response toward the right (deflection upward) and a fast saccadic movement toward the left (deflection downward). Conversely, when the stroboscopic movement occurs toward the left, the pursuit responses of the animal are toward the left, without exception. These nystagmic responses of the guinea pig duplicate in form and general temporal relations the well-known ocular nystagmus produced in many animals by real movement of visual patterns. The head nystagmus of the guinea pig displays both the pursuit and saccadic movements which are observed in eye nystagmus, and, as in the case of eye nystagmus produced by real movement, the nystagmic head movements of the guinea pig vary in frequency, within limits, as a function of the velocity of the stroboscopic movement. The records presented in Fig. 3 are representative of those obtained from thirteen normal guinea pigs. In addition similar records were obtained from the same subjects when stimulated by real movement of the striated pattern.

While giving head nystagmus, the guinea pig also at times displays eye nystagmus to stroboscopic movement of the visual field. The movements of the eyes are ordinarily more

rapid than the nystagmic responses of the head, but at the higher velocities, the head nystagmus and eye nystagmus often correspond in frequency. When the correlation does obtain, a notable pattern of head nystagmus is secured, as for example, that represented in Fig. 3 by the lower two records to the right, of Subject 109. In these two records, which were taken at stimulus velocities of 18 and 36 degrees per second toward the left, will be seen large nystagmic movements at a frequency of one every three or four seconds, superimposed upon which are smaller nystagmic reactions of a frequency of about one per second. The smaller nystagmic reactions of the head correspond exactly to the frequency of the eye nystagmus of the animal. The presence of eye nystagmus was determined by direct observation, as no method for recording the eye movements was utilized.

Many of the records obtained on normal guinea pigs show the occurrence of nystagmic reactions after termination of the period of light stimulation. In Fig. 3 such after-nystagmus appears in seven records. These responses, which are also produced by real movement, occur fairly consistently in the records of normal animals, and indicate again the close similarity between optic nystagmus produced by stroboscopic and by real movement of striated patterns.

Control observations were made on some of the normal animals when the stroboscopic movement was reduced to zero velocity by adjusting the flashing frequency of the stroboscope to fundamental synchronism with the velocity of the stripes. Under such conditions none of the animals displayed any sort of consistent movements such as have been described above.

2. *The Effect of Partial Decortication upon Responses to Stroboscopic Movement*

Three types of operations were performed which involved partial destruction of the cerebral cortex in the guinea pigs. These included removal of the occipital areas of the cortex (six animals), hemidecortication (nine animals), and hemidecortication combined with removal of the occipital area of

the other hemisphere (four animals). The four animals of the third group served as subjects in either the first or the second group after a first operation, and in the third group after a second operation (see Table 1).

The effects of removal of the occipital areas of the cortex upon the responses of the guinea pig to stroboscopic movement were found to be relatively insignificant. Satisfactory responses were given postoperatively by all six animals, although complete sets of records at all three speeds were obtained for only three of the subjects. Examination of these records shows no distinguishable differences from those secured with normal animals in magnitude of response, or in the occurrence of after-nystagmus. As will be shown quantitatively later, frequency of response increased somewhat following the operation.

Behavioral and histological observations confirmed the success of the operations, in indicating the complete bilateral removal of the visual areas of the cortex. Behaviorally, these six animals displayed visual defects similar to those which have been described in other animals after removal of the visual cortex. They often walked off elevated surfaces and could not locate food on the basis of visual cues. Histological examination of the six brains showed in each case general degeneration of the external geniculate bodies, a condition which is brought about by destruction of the visual cortex.

Following hemidecortication, records such as those which appear in Fig. 4 were obtained. The records in this figure were secured from Subject 109, in which the right cortex had been removed. It is obvious from these records that hemidecortication does not distinctly alter the nystagmic responses to stroboscopic movement in either direction. The frequency of the reactions is at least as great as in the normal animal, and the magnitude of the reactions is not greatly different. Further, the hemidecorticate guinea pigs display after-nystagmus to both directions of stroboscopic movement. In some of the hemidecorticate pigs, the rate of head nystagmus was markedly increased after the operation. For example if the results secured on Subject 109 before and after hemidecortica-

tion be compared (Figs. 3 and 4), it will be seen that the frequency of the movements at corresponding speeds was greater after the operation. In the animals in which this increase was noted, the rate of the head nystagmus corresponded almost exactly to the rate of the eye nystagmus, and the coördinated large and small nystagmic reactions, previously noted in the behavior of normal animals, were not observed.

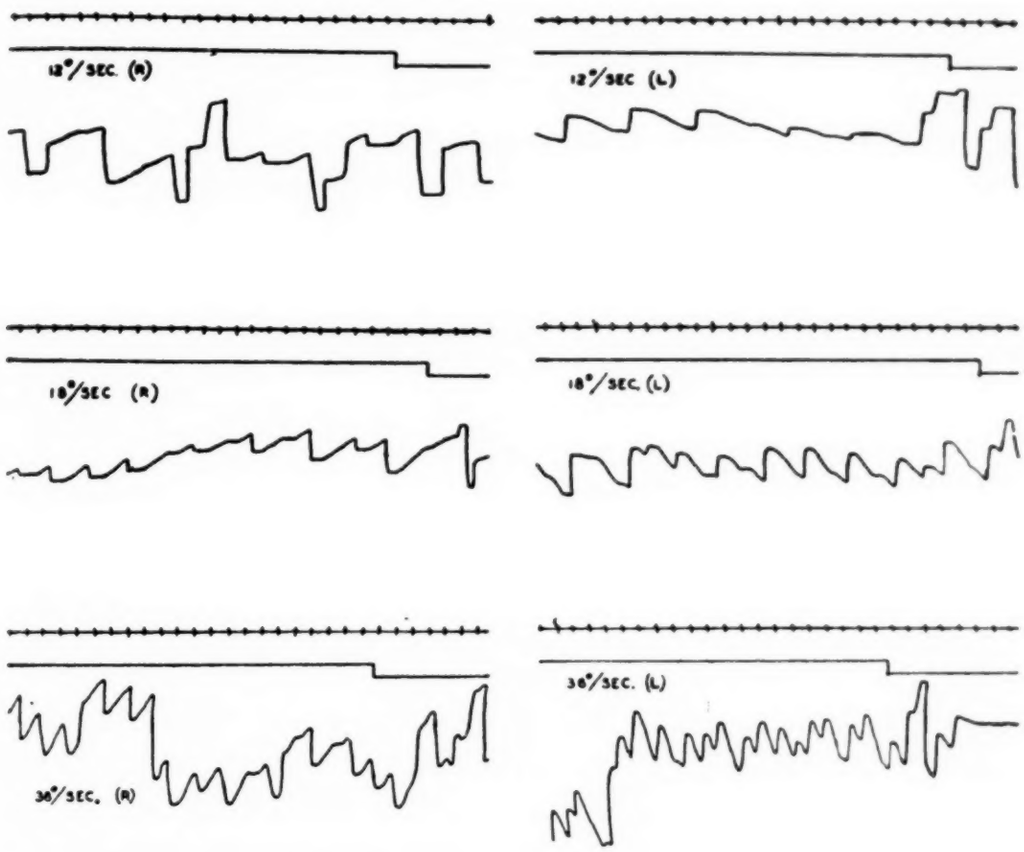


FIG. 4. Head nystagmus produced by stroboscopic movement in one guinea pig in which the right cortex had been removed.

With extensive destruction of the cortex in the guinea pig, involving hemidecortication combined with removal of the occipital area of the other henisphere, the nystagmic reactions produced by stroboscopic movement of the visual field still persist. The operation was performed upon each of the four animals in two stages. In Subjects 112, 113, and 115, the occipital areas of the cortex were first removed and the remaining cortex on the left side extirpated at a later time. In

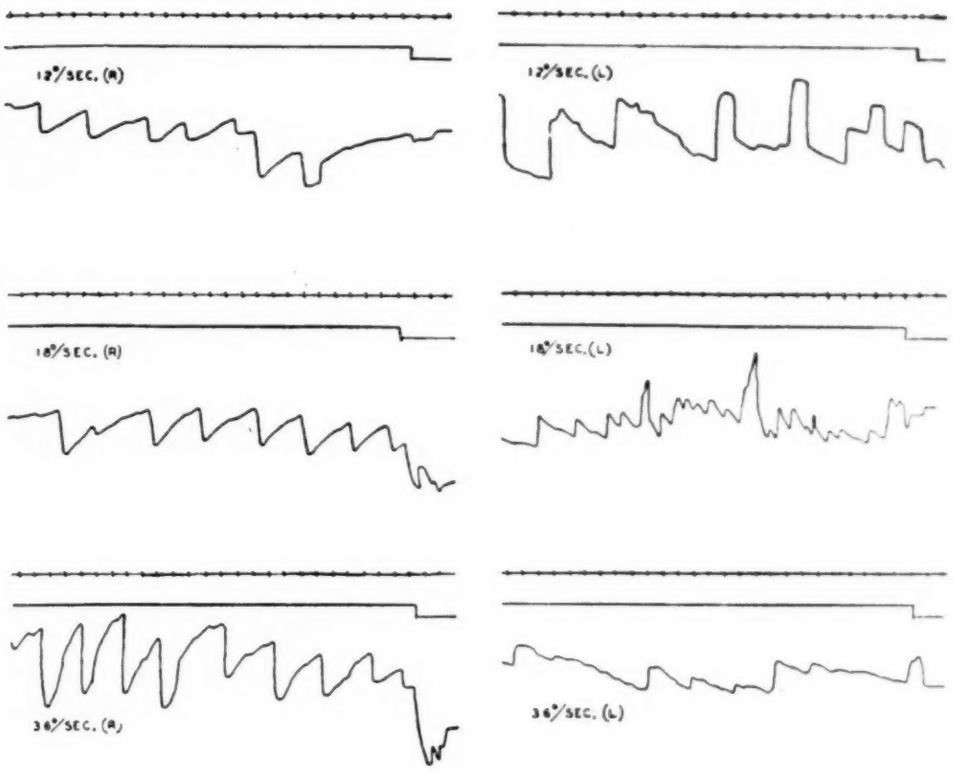
Subject 117, the right cortex was first removed, followed by extirpation of the left occipital area. The top series of records in Fig. 5 were obtained from Subject 112 following removal of the left cortex and the right occipital area. Here again there are no notable deviations from records of normal subjects in frequency of movements, although the magnitude of the movements is noticeably greater, representing a head deviation of as much as 120 degrees in some instances. The animal displays after-nystagmus at stimulus velocities of 18 and 36 degrees per second.

Reference to the lower half of Fig. 5 will show that, with removal of the remaining cortex in Subject 112, the nystagmic reactions still persist, although somewhat changed in form. The frequency of the responses is not less, but the magnitude of the responses is definitely reduced. The animal, after this third operation involving removal of almost every remnant of the cerebral cortex, displays reactions at all three velocities of stroboscopic movement, and also gives some instances of after-nystagmus (not shown in Fig. 5).

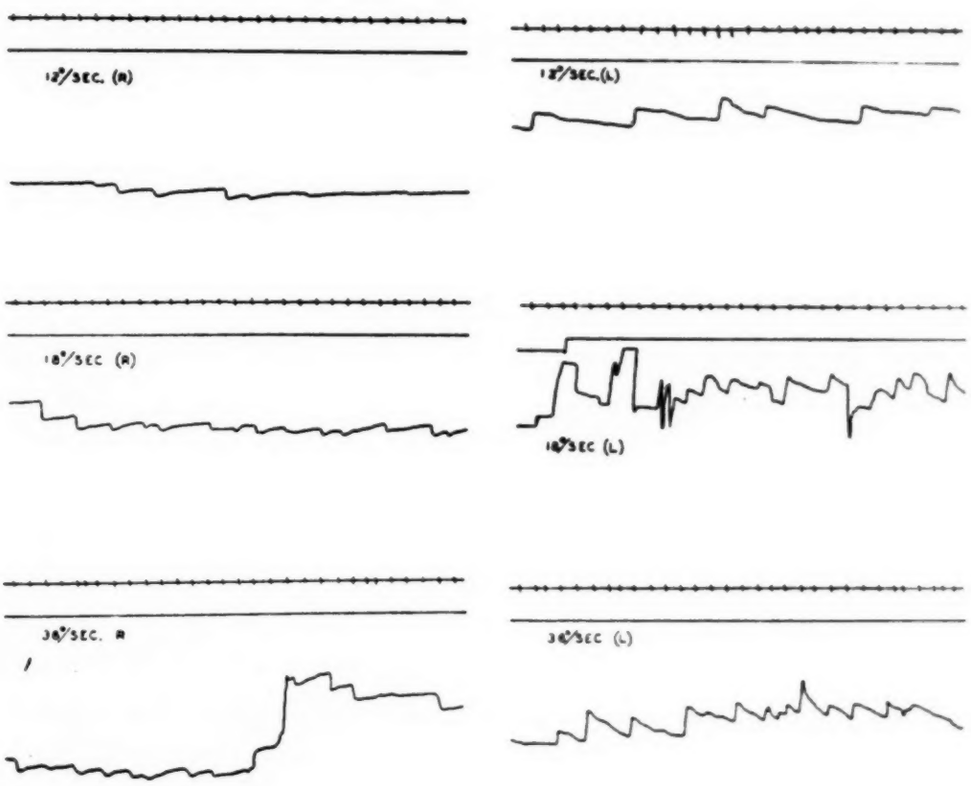
3. *The Effect of Complete Decortication upon Responses to Stroboscopic Movement*

In all, twelve decorticate guinea pigs were observed in the apparent movement situation. The cortex was removed in one stage in three animals, in two stages in seven animals, and in three stages in the remaining two animals. Most of these subjects were tested within a few hours after the cortex had been removed and also at a later time varying from two to ten days after the operation.

The results secured on two animals, Subjects 104 and 109, in which the operation was carried out in one and in two stages respectively, are presented in Fig. 6. The records given in this figure are to be compared with those presented in Fig. 5 for Subject 112, in which the cortex was removed in three stages. All of these records were secured from three to six days following the last operation. In every case responses to stroboscopic movement persist after all somatic cortex has been removed, and appear about the same whether the opera-



PIG 112 RIGHT OCCIPITAL AREA AND LEFT CORTEX REMOVED



PIG 112. DECORTICATE

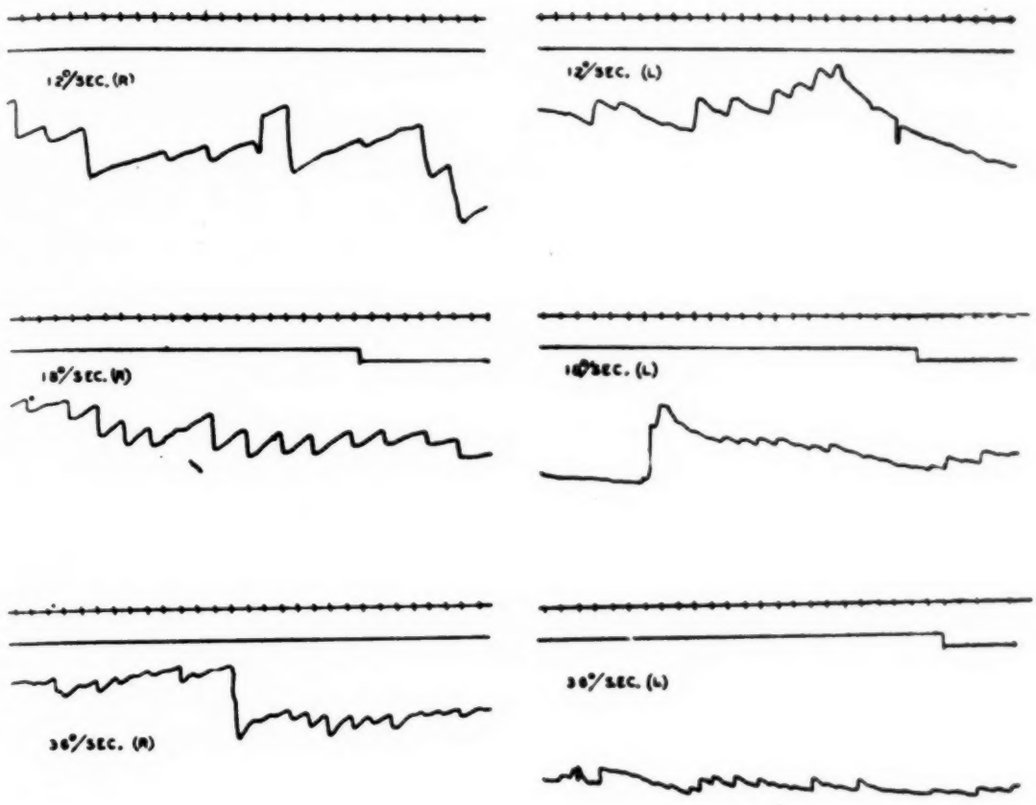
FIG. 5. Head nystagmus produced by stroboscopic movement in one guinea pig at two different stages of decortication. The upper group of records were secured after the right cortex and the left occipital area had been removed. The lower group of records were secured after complete decortication.

tion was performed in one, two, or three stages. Subject 104, in which the cortex was destroyed in one stage, displays as regular responses as does Subject 112, in which the operation was performed in three stages. Subject 109 likewise displays consistent head reactions to the stroboscopic movement.

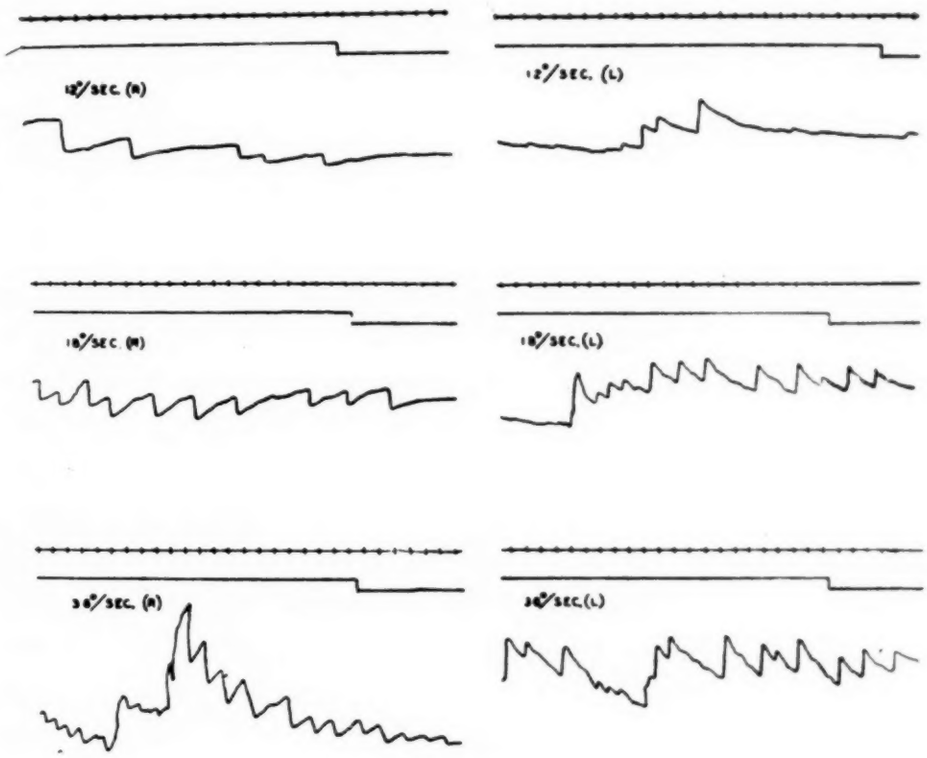
The preoperative records for Subjects 104 and 109 have been presented previously in Fig. 3. Comparison of these records with those in Fig. 6, secured after bilateral decortication, will show that certain changes occur in the nystagmic reactions after the cortex has been removed. The reactions of the decorticate guinea pigs are definitely increased in frequency but are of smaller amplitude than those observed in normal animals. The reactions of the decorticate animals, however, are as consistent as those found in the normal guinea pig. There seems to be no notable change in the initial latency of the response or in the rate of the fast phase of the responses after complete removal of the cortex. It should be noted that the records of the two decorticate animals in Fig. 6, which include the termination of their period of light stimulation, show long series of after-nystagmus movements.

Records presented previously in Fig. 4 have indicated the nature of the responses of Subject 109 after hemidecortication. Comparing these records with those obtained on Subject 109 after bilateral decortication, it is seen that there are few if any distinctive modifications in the animal's responses when the second hemisphere was removed. The most notable changes are an increase in regularity of the reactions toward the right after the left cortex was removed and a slight decrease in the amplitude of response at the higher velocities of rotation. This latter observation has already been made concerning the records of Subject 112 in Fig. 5.

The character of the responses of decorticate guinea pigs is determined to some extent by the time which has elapsed since the operation. Ordinarily, the nystagmic reactions are weak and irregular for some six to twelve hours following recovery from the anesthesia. It is not always possible to elicit them at this early stage. On the second day following the operation, however, stroboscopic movement in the visual



PIG 104 DECORTICATE



PIG 109 DECORTICATE

FIG. 6. Head nystagmus produced by stroboscopic movement in two decorticate guinea pigs.

field produces responses which are as consistent and of as great a frequency and amplitude as at any succeeding period. During the first day following the operation, the heightened activity characteristic of a decorticate animal makes it extremely difficult to restrain the subject, a fact which may partly but not wholly explain the irregular responses obtained during this time.

4. *Quantitative Summary of Results*

The correlation between frequency of reactions and velocity of stroboscopic movement for both normal and operated animals is indicated in Table 3. The numbers in the body of the table represent the maximal number of responses made over a period of fifteen seconds in any of the test periods. Velocity and direction of stroboscopic movement are given across the top of the table while the column to the left of the table indicates the condition and number of the subject. Only data for animals on which a complete series of preoperative and postoperative records were secured are included in the table.

Comparison of preoperative and postoperative data, either for individual animals or for the groups, will bring out the fact that there is a definite tendency toward increased frequency of response following the operations. For the group of hemidecorticate animals, there is a slight (though statistically insignificant) increase in frequency at all three speeds, for movement in a direction opposite the side of the lesion. When the stroboscopic movement was toward the side of the lesion, there were no consistent changes in frequency from the normal. The tendency toward increased frequency of reaction is more marked following bilateral removal of the occipital areas, and is particularly striking following bilateral decortication. Summaries of the group averages for these two conditions are given in Table 4. This table gives the mean preoperative frequencies of response at the three speeds for the animals of each group, the mean postoperative frequencies of response, the differences between the two means, the critical ratios, and the corresponding *P*-values. Those critical ratios marked

TABLE 3

THE MAXIMUM NUMBER OF RESPONSES OCCURRING IN FIFTEEN SECONDS AT THE THREE DIFFERENT VELOCITIES OF STROBOSCOPIC MOVEMENT IN NORMAL AND OPERATED ANIMALS

Subject	Rotation to Right			Rotation to Left		
	12°/sec.	18°/sec.	36°/sec.	12°/sec.	18°/sec.	36°/sec.
Normal						
102	2	7	11	1	5	6
104	6	7	9	4	6	9
107	5	7	9	4	9	10
109	3	10	11	3	5	10
112	1	4	9	1	7	8
118	3	4	4	2	5	4
119	2	2	6	3	4	7
120	4	7	6	3	9	11
Occ. Areas Removed						
112	3	9	10	5	8	10
119	5	8	11	4	7	13
120	3	9	12	2	8	11
One Hemis. Removed						
102(R)	3	4	14	5	8	10
107(R)	5	5	9	3	6	6
109(R)	4	7	15	4	9	16
118(L)	3	6	5	4	6	9
One Hemis. and Occ. A. Removed						
112(L.Hem.)	7	6	10	6	15	18
Decorticate						
104	5	8	13	8	14	15
107	6	8	17	11	9	16
109	4	8	16	5	10	19
112	6	8	9	3	12	13

TABLE 4

INCREASE IN REACTION FREQUENCY IN TWO GROUPS OF OPERATED ANIMALS

Speed in Degrees per Sec.	Occipital Areas Removed					Decorticate				
	Pre.	Post.	Diff.	CR	P	Pre.	Post.	Diff.	CR	P
12	2.3	3.6	1.3	1.5	.2	3.4	6.0	2.6	2.9*	.02
18	5.5	8.2	2.7	2.6*	.05	6.9	9.6	2.7	2.5*	.03
36	7.8	11.1	3.3	3.0*	.03	9.4	14.8	5.4	5.6*	<.005

* Statistically significant.

with asterisks (*) have corresponding values of P of .05 or less, and thus are assumed to have statistical significance. This general method for dealing with small samples has been recommended by Fisher.[4] According to the data presented in the table, there was a postoperative increase in response frequency at stroboscopic velocities of 18 and 36 degrees per second for the animals in which the occipital areas were removed, and at all three velocities, 12, 18, and 36 degrees per second, for the decorticate animals.

E. Discussion

1. *The Nature of Apparent Movement Vision in Infra-Human Mammals*

As described above, optokinetic head nystagmus has been elicited in normal, partially decorticate, and completely decorticate guinea pigs by stroboscopic movement of striated patterns with velocities of 12, 18, and 36 degrees of visual angle per second. Using these three stroboscopic velocities, the spatial separation of an individual stimulus striation upon successive flashes of the stroboscope was 0.7, 1.0, and 1.8 degrees, respectively. Polygraphic records of the head nystagmus so elicited indicate that the frequency of the responses is a function of the velocity of the stroboscopic movement. These observations are consistent with the results of previously reported experiments (Smith and Kappauf, **10**), in which it was found that ocular nystagmus may be produced in cats by similar stroboscopic stimulation.

The nystagmic head responses elicited in guinea pigs by stroboscopic movement duplicate the form of the reactions elicited by real movement stimulation, providing the nature of the lined pattern and the velocity of the seen movement are comparable in the two cases. The similarity of the responses is such that it is impossible to tell the nature of the stimulation from an examination of the nystagmus records alone. This means that both types of stimulation produce reactions of similar frequency, latency, amplitude, and regu-

[4] Fisher, R. A. *Statistical Methods for Research Workers.* 5th ed. Edinburgh: Oliver and Boyd, 1934. Pp. xiii + 319.

larity, and seem to be equally effective in bringing about after-nystagmus.

All the experimental observations summarized above seem to indicate that the responses of guinea pigs (and cats) to stroboscopic movement constitute a type of movement vision not discernibly different from that related to real movement of stimulus patterns. From the data at hand, there is every reason to believe that stroboscopic movement of visual patterns is as 'real' to the animal as continuous movement of the same patterns. It is plausible to assume that the apparent movement vision of animals is functionally similar to that of man, for, as far as could be determined, the conditions of stroboscopic stimulation which produce nystagmus in guinea pigs are the circumstances under which the human eye observes apparent movement, while those conditions of stroboscopic stimulation which fail to produce nystagmus in the animal also fail to give the impression of movement to the human eye.

The present results seem significant in suggesting that the capacity for apparent movement vision is a fundamental aspect of mammalian vision and is not, as has been implied in some theories, a perceptual capacity based primarily upon some process of learning or acquired perceptual interpretation (Piéron, **5**). The appearance of apparent movement vision in completely decorticate animals strongly implies the primitive nature of the function.

2. *Types of Visual Receptors and their Relation to Apparent Movement Vision*

In the last few years evidence has accumulated that the ability to respond to stroboscopic movement is limited by the nature of the visual system. In a number of experiments on invertebrate animals, Gaffron (**3**) has shown that responses to stroboscopic movement do not occur in animals possessing compound eyes when the spatial separation of the successively presented stroboscopic pattern exceeds the visual angle subtended by individual facets of the eye. On the basis of these results, Gaffron concludes that no true apparent movement

vision exists in dragon-fly larvæ and flies. However, it has been shown by Gaffron that fish give clear optokinetic responses to stroboscopically presented movement. Schiller (**6**) corroborates these results on fish, showing that a fish can be trained to respond on the basis of apparent movement vision. These data, combined with the results described above on the guinea pig and the cat, suggest that apparent movement vision is typical of the vertebrate visual system.

3. *The Neural Mediation of Apparent Movement Vision*

The main purpose of the present experiment was to determine, as far as possible, the neural centers concerned in the mediation of apparent movement vision in the guinea pig. Results obtained relative to this problem indicate that operative lesions which destroy the cortical projection areas of the retina have no detrimental effect upon the capacity of the animal to respond to stroboscopic movement. Six animals in which the striate areas of the cortex were destroyed bilaterally displayed reactions to stroboscopic movement as consistent as and somewhat more frequent than those found in normal animals. These observations confirm previously reported results on the cat, which showed that ocular nystagmus produced by stroboscopic movement of the visual field is not markedly disturbed by the removal of both visual areas of the cortex (Smith and Kappauf, **10**). Extirpations involving removal of one hemisphere of the cortex seem to influence only slightly the nature of the guinea pig's responses to stroboscopic movement. The only discernible change was a slight (statistically insignificant) increase in frequency of response when the stroboscopic movement was in a direction opposite the side of the lesion. Animals deprived of one hemisphere and the opposite occipital area are comparable to the animals deprived of both occipital areas. No marked changes were noted except increased frequency of response in both directions.

Observations on the effect of partial cortical lesions were supplemented by careful investigation of apparent movement vision in twelve bilaterally decorticated guinea pigs. Using data of the four animals from which complete series of pre-

operative and postoperative records were secured, it has been shown that there is a statistically significant increase in frequency of the nystagmic reactions at all three velocities of stroboscopic movement. However, the decorticate animals displayed a slight reduction in magnitude of response at all velocities of movement. Every animal in this group responded consistently to stroboscopic movement in every test given after the first day following the operation. There can be no doubt as to the discriminative nature of the response, as the nystagmic pursuit phase was always correlated with the direction of the stroboscopic movement. Of the twelve guinea pigs in this group, decortication was carried out in one stage on three animals, in two stages on seven animals, and in three stages on two animals. These differences in the procedure of the operation seemed to have no influence on the nature of the responses to stroboscopic movement recorded two to four days after the final operation had been carried out.

The phenomenon of post-stimulation nystagmus or after-nystagmus occurs in normal animals following stimulation by both real and stroboscopic movement. This fact is of some importance since the occurrence of such reactions can possibly be taken as an indicator of the effectiveness of the nystagmus-producing stimulation. Inasmuch as after-nystagmus was observed as frequently in postoperative as in preoperative tests, we may assume that the stroboscopic stimulation lost none of its effectiveness for the animals following cortical operations. In fact, as some of the records in Fig. 6 indicate, post-stimulation nystagmus seems to occur more frequently and to last for longer periods of time in the decorticate than in the normal animal.

Since the data presented leave little doubt that apparent movement vision occurs in the absence of all somatic cortex, it is of interest to inquire into the possible subcortical centers and pathways involved in responses to stroboscopic movement. Available anatomical and physiological knowledge suggests that the pretectal nuclei and the centers of the superior colliculi are the significant subcortical stages of integration which are involved in the complicated processes of excitation and inhibition demanded for nystagmic pursuit to

stroboscopic movement. In related observations of the writer (**8**) on the rôle of the superior colliculi in the mediation of optic nystagmus to real movement stimulation, it has been shown that each colliculus is primarily concerned with the determination of nystagmic reactions, the pursuit phases of which are toward the ipsilateral side. That is, the right superior colliculus mediates primarily responses to movement toward the right, and vice versa. In addition to the determination of these directional characteristics of optic nystagmus, the colliculi may also play some rôle in the fusional processes basic to apparent movement vision. But it should be emphasized that the eye movement centers and related nuclei of the brain stem may likewise be involved in these fusional processes, for these centers are undoubtedly significant in the production of nystagmus, whether of ocular or of vestibular origin.

The phenomenon of apparent movement vision is presumably understandable only in terms of some integrational fusion process either within the retina or at some higher level of the visual system. Accordingly, the present results are significant in showing that fusion of neural impulses occurs at some stage of the visual system below the level of the cortex. At the same time, these results argue against any sort of neural or retinal streaming effects as the basis of optic nystagmus. This is evident from the fact that the stroboscopic flashes used in the present sutdy had a duration of a few microseconds, and thus provided a type of pattern presentation which was essentially stationary but which appeared on different parts of the animal's retina in a given temporal sequence.

In view of the results of the present experiment, certain of the previously expressed theories concerning the neural basis of apparent movement vision are found to be inadequate. The belief of Wertheimer (**13**) that apparent movement vision is dependent upon cortical processes of diffusion and short-circuiting obviously fails to account for the subcortical functions demonstrated here, although certain aspects of apparent movement vision, such as binocular integrations, may require the functioning of an intact cortex. The data of the present study, contrary to the ideas expressed on this subject by a

number of Gestalt psychologists, indicate that the general phenomenon of apparent movement vision is related to certain of the more primitive subcortical reflex functions, and does not demand the postulation of any special neurological mechanism associated with cortical processes. The phenomena of neural interaction which have been found to occur within the retina and possibly also at other stages of the central visual system (Bartley, 1) seem to provide a sufficient explanation for many of the facts observed in connection with apparent movement vision. It is the opinion of the writer that the demonstrated capacity of decorticate animals for responding to stroboscopic movement relieves one of the necessity for utilizing other than known neural mechanisms as a basis of explanation.

F. Summary

1. Stroboscopic illumination of a moving striated pattern which covers almost the entire visual field is effective in producing in the guinea pig differential nystagmic reactions, the frequency of which is a function of the velocity of the stroboscopic movement.

2. The character of the nystagmic responses of the head produced in guinea pigs by means of stroboscopic movement duplicates in almost every detail similar responses elicited by real movement.

3. Results of extirpation experiments indicate that removal of the occipital areas of the cortex in the guinea pig does not markedly alter the nature of the animal's responses to stroboscopic movement, although the frequency of response is somewhat increased following the operation. Hemidecortication does not alter the nature of the responses in any significant way. Hemidecortication combined with removal of the occipital area of the opposite hemisphere produces results comparable to those following removal of the occipital areas alone.

4. Responses to stroboscopic movement persist in the guinea pig after complete bilateral decortication. In the decorticate animals there is a significant increase in the frequency of the responses and some reduction in amplitude following the operation.

5. The results of the experiment indicate beyond doubt that the capacity for apparent movement vision persists in the guinea pig after the destruction of the cortical projection centers of the retina and after all somatic cortex has been removed.

6. If apparent movement vision be understood as constituting a type of neural fusion and interaction within the visual system, as it presumably must be, one may conclude that the present observations offer proof of the occurrence of neural interaction and fusion below the level of the cortex.

7. The significance of the present data for the general theory of apparent movement vision lies in the demonstration of the phenomenon as a function of the subcortical reflex systems.

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AN EXPERIMENTAL INVESTIGATION OF MEMORY SPAN

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The present study is concerned with the relative constancy of the memory span. In the literature there is no definite evidence as to whether memory span is general or specific, *i.e.*, whether the span of an individual remains constant relative to that of the other members of the group in spite of the variations due to the influence of other factors. In this investigation two factors were varied at different times, namely, the type of material and the sensory avenue of presentation. The object was to investigate the constancy of the individual in relation to the group under these two conditions.

At the same time the data also yield information on the absolute constancy of the memory span. In the earlier literature the general belief was that there was a constant absolute size of memory span, *i.e.*, that the size of the span did not vary with the material presented. Blankenship (1), in a recent summary of the literature, presents evidence to prove that the absolute size of the span varies from material to material. The present study lends further evidence to this latter conclusion. It may be noted in passing that should there be an absolute constancy, that is, should the size of the memory span be independent of the type of material then the question of relative constancy would be automatically solved, and memory span would of necessity be general rather than specific.

Plan of the Experiment

Materials and Method of Recall

Tests were constructed with ten different kinds of material. The materials are listed below with explanations as to the procedure followed in constructing the tests.

* The writer wishes to express his appreciation to Dr. H. A. Carr, Dr. F. A. Kingsbury, and Dr. L. L. Thurstone for their guidance and assistance during the course of this study. He also wishes to thank Mr. Ledyard R. Tucker for his suggestions of procedure in the factorial analysis on which the latter part of the study is based.

However, in order to clarify the procedure and the general set-up of the experiment a few words of explanation are given on the terminology used to describe the tests. Each test was composed of a variable number of units. In the digit test, for example, each digit was a unit; in the sentence test each sentence was a unit, etc. The units were organized into series of varying lengths. In some tests the minimum length of a series was one unit; in some tests the maximum length was thirteen units. The presentation of a series to the subject constituted a trial. In all the tests except two each unit was typed on a separate 3″ × 5″ card. In the two remaining tests 3″ × 5″ cards were also used. However, in one of the tests, the test of Geometrical Designs, each unit was drawn on a card rather than typewritten. In the other test, the test of Colors, each unit was pasted on a separate card.

Digits.—In the digit test, as already indicated, each digit was a unit. Ten series of four units were constructed, ten series of five units, ten series of six units, etc., up to and including ten series of thirteen units. In all other tests, likewise, ten series were constructed for each unit length. In constructing the various series for the digits the usual precautions were observed. An attempt was made to avoid common associations such as historical dates, the current year, etc. No digit was placed next to one immediately following or preceding it in the usual order of counting; *e.g.*, the number seven was never placed after six or eight. No digit was repeated in any one series except where there were more than nine units to the series. The method of recall of the series of digits was oral reproduction. This method of recall was used for all of the tests except the test of Memory for Commissions. At the conclusion of each series the subject was supposed to repeat the digits in the order of their appearance in the series.

Nonsense Syllables.—Each nonsense syllable constituted a unit. Series for this test varied in length from one to six units inclusive. All of the nonsense syllables used in this test were chosen from Glaze's (3) list of syllables having associational values ranging from 40 percent to 53.33 percent. In reproducing any given series the subject was instructed to spell out the three letters of each nonsense syllable rather than to pronounce the syllable.

Consonants.—Each consonant constituted a unit. The series varied in length from four to thirteen units inclusive. In constructing the series the same general rule was followed as for digits, with the additional consideration that no series contained the same unit twice. Likewise, in recall the procedure was the same as for digits.

Geometrical Designs.—The following figures or designs were used: oval, triangle, square, spade, heart, diamond, trapezoid, circle and semi-circle. Each design constituted a unit. The series varied in length from four to nine units inclusive. The designs were drawn in India ink on 3″ × 5″ cards. All of the designs were made as nearly equivalent in area as possible. The area per design was approximately one-half square inch. In recalling any series the subject was supposed to repeat the names of the designs in their proper order.

Colors.—The following colors were used: red, orange, yellow, green, blue, white, purple, black and gray. Strips of color one-fourth by one inch were cut from sheets of paper ordinarily used in color vision experiments. Each strip was pasted on a card 3″ × 5″ to constitute a unit. The series varied in length from four to ten units inclusive. Again, the subject reproduced orally the names of the colors in the order of their appearance.

Concrete Words.—Each unit was a four letter concrete noun, *e.g.*, goat, hand, doll, etc. The series varied in length from four to ten units inclusive. Special care was taken to avoid alphabetical arrangement of the units and obvious associations such as

hand, foot, etc. At the conclusion of a series the subject repeated the words in the order of their appearance.

Paired Associates.—The unit was a combination of a three letter concrete noun and a two digit number, *e.g.*, boy-31. The series varied in length from two to five units inclusive. In recall the subject had to repeat orally the noun and its corresponding number, each unit in its proper order.

Abstract Words.—The unit consisted of a five, six, or seven letter abstract noun of one or two syllables. In constructing the series for the test the units were chosen so that every series of a given unit length contained exactly the same number of letters and the same number of syllables. For example, each of the ten series of four-unit length contained eight syllables and twenty-four letters; each series of five-unit length contained nine syllables and thirty-two letters, etc. The series varied in length from four to nine units inclusive. The procedure in recall was the same as for concrete words.

Memory for Commissions.—The unit in this test consisted of a simple command. An example of such a unit is the following: "Put a circle around A." Another is: "Put a comma below B." Each unit was five or six words in length. The series varied in length from one to five units inclusive. As mentioned above the method of recall in this test differed from the others. Instead of repeating the commission orally the subject performed the task on a card placed before him for that purpose. As in the other tests, however, each commission was to be performed in the order of its appearance in the series.

Simple Sentences.—In this test a simple declarative sentence constituted a unit. Each sentence consisted of six words in eight syllables. An example of a unit is the following: "Mary waved to the cheering crowd." The series varied in length from one to five units inclusive. In recalling each series the subject was to repeat each unit, *i.e.*, each sentence, verbatim and in its proper order in the series.

Auditory Tests.—In addition to the ten visual tests listed above, there were also three auditory tests—tests for consonants, concrete words and abstract words. The same procedure was followed in constructing these tests as in constructing the visual tests for the same materials. In fact, the tests were identical except for a rearrangement of the units in the various series. As in the visual tests the method of recall was oral reproduction.

Method of Presentation

In the visual presentation of the test material to the subject the following procedure was adopted throughout the experiment: the subject sat at a table opposite the experimenter who was hidden from view by a black cloth screen. The cards containing the units of material were shown to the subject through an exposure apparatus at the rate of one card every two seconds. This rate of exposure, two seconds per unit, was maintained throughout the experiment. Since the cards were fed into the exposure apparatus by hand, a special device was set up to assure as accurate timing as possible. An electrically controlled metronome clicking at the rate of once every two seconds was enclosed in a sound box. The sound of the metronome was conducted to the experimenter by a set of ear-phones. The actual experiment was not begun until the experimenter had had sufficient practice in synchronizing the dropping of the card with the clicking of the metronome.

Before the presentation of any series the subject was told how many units the series contained. He was also given a warning signal approximately one second before the presentation of the first unit of the series. In order to make sure that the same

exposure time was allowed for the last unit of a series as for the others the subject was told not to repeat the series to the experimenter until the appearance of a blank card after the last unit of the series. For example, if a series consisted of five units, each unit being visible for two seconds, the fifth card was followed by a blank card at an interval of two seconds. Immediately on the appearance of the blank card the subject repeated the entire series. It was further emphasized in the instructions to the subject that in those cases where he could not repeat the entire series he was to give as much of it as possible in proper order, indicating the omitted units by saying the word 'Blank.'

The order in which the tests were presented to the subject is the order in which they are listed above. The same order was used for all subjects so that practice effect would be as nearly constant as possible.

In the digit test, which was the first, the subject was given ten series of six units each. If he got all ten series correct, he was then given ten series of seven units length. If, however, he failed in any of the series of six units length, he was given ten series of five units length, etc., in descending order until the point was reached where all ten series of a given unit length were repeated correctly. The unit length at which all the ten series were given correctly is referred to as the 'basal level.' After the basal level had been established, the subject was then given ten series of each unit length for which he had not yet been tested until the point was reached where he failed all ten trials of a given unit length. An example is herewith given of the order of presentation of the series to Subject B in the digit test. Subject B was given the ten series with six units per series and repeated six of the ten series correctly. He was then given the ten series of five units and responded correctly on eight. Next followed the ten series of four units, on which he repeated all the series correctly. The series of four units length constituted the basal for Subject B. Next followed ten trials of seven units length, four of which were given correctly. Three of the series of eight units length were correct, one of the series of nine units length was correct, and none of the series of ten units length were correct. This concluded the digit test for Subject B.

The same general procedure was followed for all of the visual tests, except the test of memory for commissions. The administration of the auditory tests differed from the visual only in that the material was read by the experimenter. But the rate of presentation, the number of series, the number of units per series, and the mode of response were the same for the auditory and visual tests.

As already mentioned, the only noteworthy deviation from the above procedure was in the test of memory for commissions. Accordingly, the procedure for this test is herewith outlined. A card was placed before the subject on which were printed in ink certain symbols, *e.g.*, the letters A and B or the digits two and three, or combinations of letters and digits. A pencil was placed before the subject along with the card. The subject was then told to attend to the exposure apparatus, and after the usual warning signal, the units of each series, that is, the commissions or the commands, were presented exactly as were the units of every other test. Upon the appearance of the blank card which indicated the close of the series, the subject picked up the pencil and performed the operations on the symbols on the card before him. As in the other tests, there were ten series for each unit length.

The length of time for the completion of a test varied from test to test and from individual to individual. Those tests in which the units were complex, such as the test of Sentences and the test of Memory for Commissions, took a relatively short time, since the subjects failed on all ten series where only three or four units were involved. Those tests in which the units were less complex, such as the test for Digits

and the tests for Consonants, took a longer time. Likewise, subjects who did the best took the longest time. With practically all the subjects the thirteen tests were completed in four or five sessions of about one hour each. In the case of a few of the highest scoring subjects a sixth session was required. No limitations were placed on the number of days between sessions, but for each subject the time of day during which the experiment was conducted was held constant within a few hours. In no cases were subjects tested at one time early in the morning and the next time late in the afternoon.

In the final experiment forty subjects were used. All of the subjects were students of the University of Chicago.

Method of Scoring

Guilford and Dallenbach (4) list twenty-seven methods of scoring tests of memory span. It is obvious that the choice of a method is arbitrary. The feature which determines whether a method is good or not is the degree to which it is capable of distinguishing between subjects.

In the present study the following procedure was used. A series was scored either right or wrong. Every unit of a series had to be repeated by the subject verbatim and in the order in which it was presented in order to earn credit. Any deviation from the above made the series wrong. One-tenth of a point (.1) was given for a correct series. No credit was given for a wrong series. As an initial score, the subject was given the number of points corresponding to the number of units in his basal level. If a subject had a basal level of four in a given test, he was given an initial score of four points. One-tenth of a point (.1) was added to the initial score for every correct response thereafter. The sum total of the initial score plus the credit for the correct responses above the basal level constituted the subject's score for that particular test.

Below is given the score of Subject B, mentioned above, in the Digit Test.

Units per Series	Number of Trials	Number Correct	Score
4	10	10	4.0
5	10	8	.8
6	10	6	.6
7	10	4	.4
8	10	3	.3
9	10	1	.1
10	10	0	.0
Total Score			6.2

Scores for each subject in all thirteen tests were obtained in the same way.

As stated above, series were scored either right or wrong. No credit was given for partially correct responses. However, in view of the fact that the subjects were instructed to repeat as many units as they could in a given series even though they knew part of the series was wrong, it was felt that a score based on credit for partially correct responses might yield some interesting results. Accordingly, four of the tests were scored in this additional way with credit being given for partially correct responses. The four tests thus scored were Nonsense Syllables, Paired Associates, Memory for Commissions, and Sentences.

In the test of Nonsense Syllables each syllable contained three letters. By the second method of scoring the subject was given one point for each letter correctly repeated. In a series of two units the subject could make a maximum score of six

points. If one letter in such a series were missed, the subject was given a score of five points, if two letters were missed, four points, etc. It should be noted that not all of the subjects were tested on the same number of series. Some of the subjects missed all ten series of four-unit length and were not tested on the series of five-unit length. Therefore in scoring by the second method it was important that only those series be included in which every subject had been tested. The same precaution was followed in scoring the other three tests.

In the test of Paired Associates each unit gave a maximum score of two points—one for the word and one for the number accompanying it. For example, if for the unit, 'boy-31,' the subject said, 'boy-32' or 'man-31,' he was given only one point for the unit. In a two-unit series the maximum score was four points; in a three-unit series six points, etc.

In the test of Memory for Commissions each unit was given a maximum value of three points—one for each operation involved in the unit. For example, in the command, "Put a comma under A," the subject had three operations to bear in mind. One was the use of the correct operational symbol. The subject could have used a colon or a plus sign or a minus sign instead of a comma. He also had to remember the position of the operational symbol, since he could have placed it above, beside, or in the letter rather than below it. Finally, he had to remember the letter on which the operation was to be performed. He could have put the comma below B or C instead of below A. He was therefore given one point for each of these correct operations, or a maximum of three points per unit.

In the test of Sentences each unit was given a maximum value of six points—one point for each word in the sentence. A two-unit series gave a maximum score of twelve points; a three-unit series, a maximum value of eighteen points, etc.

In each of these four tests the final score was the total number of points earned.

Results and Interpretation

The data yield information on the comparative magnitude of the memory span for the different materials and for the two sensory avenues, the visual and the auditory.

Table 1 contains the mean score for each of the seventeen tests, the standard deviations of the scores, and the standard errors of the means.

It should be noted that the tests numbered from fourteen to seventeen inclusive are not comparable to the first thirteen in terms of actual size of span, since the first thirteen tests were scored in terms of units and the remaining four in terms of the number of parts in each unit.

Differences in memory span for different kinds of material were reported by Calhoon (**2**), Lumley and Calhoon (**5**), Squire (**6**), Warden (**11**), and others. In no case, however, were the conditions of the experiments similar enough to justify a direct comparison of actual figures representing the

TABLE 1

TABLE OF MEAN RAW SCORES AND VARIABILITY FOR EACH TYPE OF MATERIAL

Test	Mean	σ	Standard Error of Mean
1. Digits	7.98	1.112	.176
2. Nonsense Syllables (whole)	2.49	.353	.056
3. Consonants (visual)	7.30	1.200	.190
4. Geometrical Designs	5.31	1.010	.160
5. Colors	7.06	1.130	.179
6. Concrete Words (visual)	5.76	.876	.139
7. Paired Associates (whole)	2.50	.804	.127
8. Abstract Words (visual)	5.24	.763	.121
9. Memory for Commissions (whole)	2.42	.343	.054
10. Sentences (whole)	1.75	.320	.051
11. Consonants (oral)	7.21	1.065	.168
12. Concrete Words (oral)	5.86	.807	.128
13. Abstract Words (oral)	5.58	.811	.128
14. Nonsense Syllables (parts)	203.85	28.390	4.172
15. Paired Associates (parts)	125.40	18.830	2.977
16. Memory for Commissions (parts)	192.60	25.590	4.046
17. Sentences (parts)	275.90	30.990	4.900

spans for different kinds of materials. Among the factors that varied from experiment to experiment were the ages of the subjects, the length of time of exposure of the material, method of presentation, method of measuring retention, method of scoring, etc. Blankenship (1), on the basis of a survey of the literature, reports the order of difficulty to be nonsense syllables, letters, digits, and finally sentences and related words. A survey of Table 1 shows that digits seem to be the easiest to remember, with consonants and colors next in order, there being little difference between consonants and colors. Following are concrete words, geometrical designs, and abstract words. No clear differentiation should be made in the order of difficulty of the latter three. The differences between them are not great, and it is not at all unlikely that if the concrete words were made a little longer, or the geometrical designs a little simpler, the order would be reversed. The same holds true for abstract words and geometrical designs, and for abstract words and concrete words.

The last group, the most difficult, are paired associates, nonsense syllables, memory for commissions, and simple sentences. Again, as in the previous group, no definite order of

difficulty should be indicated, since slight changes in the difficulty of the units involved would change the order.

It may be noted that if a nonsense syllable is considered as a group of three letters rather than as a single unit, the mean score becomes 8.47 (3 × 2.49—which is the score for nonsense syllables treated as a unit) as compared to 7.30 which is the mean score of consonants. One possible explanation for this difference in mean scores is the fact that the middle letter of each nonsense syllable is a vowel. Since the choice of vowels is more limited than the choice of consonants, the chance of error is accordingly less. Likewise, multiplying the mean sentence score by six (which is the number of words per sentence) gives a mean score of 10.50 for meaningfully grouped words as compared to a mean score of 5.76, the score for concrete words presented singly. On the other hand, attention should be called to the fact that the difference between grouped letters and single letters and between grouped words and single words is complicated by the difference in length of exposure time. In the case of single letters the total time of exposure of three letters was six seconds. In the case of grouped letters (nonsense syllables) the total time of exposure was two seconds. Also, in the case of discrete concrete words the total time of exposure of six words was twelve seconds. In the grouped series of words, *i.e.*, in the sentences, the time of exposure for six words was two seconds.

Finally, a comparison can be made between the two different sensory avenues. Table 1 shows that there is no significant difference between consonants presented visually and orally, or between concrete words presented visually and orally, and that there is only a slight difference between abstract words presented visually and orally.

The second question to be considered is the generality or specificity of the memory span, *i.e.*, the constancy of the span of an individual in relation to the members of the group, where the only variable manipulated is the kind of material in the various tests or the sensory avenue of presentation. As will be shown in further consideration of the results, the question of the relative constancy of the span of the individual or of the

generality or specificity of the span is intimately tied up with the question of the number of separate abilities called for by all of the tests of the battery.

If there is only one general memory span factor involved, that is, if the individual's relative position in the group depends entirely on one ability that is called for in all of the tests and is not influenced by the type of material on which the span is tested, we would expect the distribution of the mean standard scores for all subjects to be fairly well scattered from high positive to high negative values. Likewise, we would expect any subject to have approximately the same standard score on all tests, with little variability in the score. Conversely, if the influence of a general memory span factor were negligible, and the individual's position in the group is dependent on separate abilities called for by the different tests, we would expect the distribution of the mean standard scores for all of the subjects to cluster around zero. We would further expect a widely scattered group of standard scores for any one subject. In the limiting case where there would be no correlation between the different scores the standard deviation would tend to approach the limiting value of 1.00, and the standard error of the standard scores of the subject would tend to approach the limiting value of .171. (Substituting in the formula

$$\sigma_\sigma = \frac{\sigma \text{ distribution}}{\sqrt{2N}},$$

where N is 17, as in this case, the limiting value would be .171.)

An examination of Table 2 shows that a point in between the two suppositions mentioned above is approximated. The distribution of the means of the standard scores is fairly wide, ranging from -1.31σ to $+1.77\sigma$. Further, on examination of the means and sigmas for each subject, it is seen that the standard deviation of the standard scores range from .363 to .799 with an average for all forty subjects of .531, and that the standard error of the standard scores ranges from .050 to .131 with an average for all forty subjects of .091.

The above results suggest the conclusion that all of the tests call for a common ability, thus tending to keep the posi-

tion of the individual constant in relation to the rest of the group, but also that certain abilities are called for in some of the tests and not in others, thus tending to make the position of the individual fluctuate in relation to the rest of the group.

A factorial analysis of the table of intercorrelations of the tests tends to bear out this conclusion.

TABLE 2

TABLE OF MEAN STANDARD SCORES AND VARIABILITY FOR ALL SUBJECTS

Subject	Mean Standard Score	σ of Distribution	σ_σ	Subject	Mean Standard Score	σ of Distribution	σ_σ
1	.97	.607	.104	21	1.38	.604	.103
2	−1.31	.749	.128	22	.73	.446	.076
3	1.77	.553	.095	23	− .40	.700	.120
4	−1.31	.543	.093	24	1.00	.428	.073
5	.09	.569	.098	25	.45	.456	.078
6	− .62	.551	.094	26	.06	.393	.067
7	− .12	.602	.103	27	− .83	.799	.137
8	− .15	.566	.097	28	− .09	.477	.082
9	.96	.428	.073	29	− .01	.630	.108
10	− .72	.462	.079	30	1.23	.612	.105
11	.66	.390	.067	31	−1.00	.651	.112
12	.12	.598	.103	32	−1.24	.476	.082
13	.39	.516	.089	33	− .74	.468	.080
14	− .30	.427	.073	34	1.14	.651	.112
15	− .44	.747	.126	35	− .49	.451	.077
16	.07	.514	.088	36	− .87	.587	.101
17	.97	.363	.062	37	.47	.542	.093
18	.20	.364	.062	38	.92	.434	.074
19	− .41	.402	.069	39	− .75	.609	.104
20	− .92	.516	.089	40	− .86	.390	.067

Factorial Analysis

Table 3 contains the intercorrelations of all of the tests. The intercorrelations were computed from the standard scores by the method of rank differences. The correlation matrix was factored by the centroid method, giving the centroid matrix of Table 4. Rotational procedure was then applied to the centroid matrix maximizing the number of zero or near zero projections on the several planes. Table 5 contains the transformation matrix by means of which the rotated factorial matrix of Table 6 was obtained from the centroid matrix. Table 7 shows the correlations between the final primary abilities.

TABLE 3

TABLE OF INTERCORRELATION OF THE TESTS

	Digits	Nonsense Syllables (Whole)	Consonants (Visual)	Geometrical Designs	Colors	Concrete Words (Visual)	Paired Associates (Whole)	Abstract Words (Visual)	Memory for Comm. (Whole)	Sentences (Whole)	Consonants (Oral)	Concrete Words (Oral)	Abstract Words (Oral)	Nonsense Syllables (Scored for Parts)	Paired Associates (Scored for Parts)	Memory for Comm. (Scored for Parts)	Sentences (Scored for Parts)
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	—	.71	.88	.74	.71	.69	.71	.66	.40	.54	.86	.73	.71	.60	.69	.48	.53
2	.71	—	.77	.65	.77	.72	.79	.78	.67	.71	.80	.76	.75	.61	.88	.59	.64
3	.88	.77	—	.80	.86	.82	.76	.77	.56	.54	.87	.75	.75	.67	.74	.53	.57
4	.74	.65	.80	—	.85	.72	.82	.78	.52	.49	.77	.62	.69	.75	.61	.56	.60
5	.71	.77	.86	.85	—	.81	.83	.84	.64	.57	.74	.70	.69	.78	.72	.62	.69
6	.69	.72	.82	.72	.81	—	.76	.86	.65	.67	.77	.83	.83	.63	.72	.50	.69
7	.71	.79	.76	.82	.83	.76	—	.86	.56	.60	.79	.68	.80	.86	.71	.56	.69
8	.66	.79	.77	.78	.84	.86	.86	—	.66	.66	.80	.82	.86	.80	.73	.54	.73
9	.40	.67	.56	.52	.64	.65	.56	.66	—	.65	.57	.62	.61	.59	.62	.74	.65
10	.54	.71	.54	.49	.57	.67	.60	.66	.65	—	.61	.71	.72	.49	.53	.49	.80
11	.86	.80	.87	.77	.74	.77	.79	.80	.57	.61	—	.82	.85	.70	.74	.57	.56
12	.73	.76	.75	.62	.70	.83	.68	.82	.62	.71	.82	—	.87	.58	.75	.45	.60
13	.71	.75	.75	.69	.69	.83	.80	.86	.61	.72	.85	.87	—	.70	.73	.52	.63
14	.60	.61	.67	.75	.78	.63	.86	.80	.59	.49	.70	.58	.70	—	.57	.64	.65
15	.69	.88	.74	.61	.72	.72	.71	.73	.62	.53	.74	.75	.73	.57	—	.64	.48
16	.48	.59	.53	.56	.62	.50	.56	.54	.74	.49	.57	.45	.52	.64	.64	—	.59
17	.53	.64	.57	.60	.69	.69	.69	.73	.65	.80	.56	.60	.63	.65	.48	.59	—

TABLE 4

CENTROID MATRIX

	I	II	III	IV	V	h^2
1	.811	.298	−.051	.097	.272	.833
2	.880	.061	−.228	.079	.041	.848
3	.882	.290	.044	.133	.163	.908
4	.833	.114	.285	.152	.072	.816
5	.893	.041	.270	.136	.032	.892
6	.883	.110	.048	−.230	−.064	.851
7	.890	.063	.242	.058	−.069	.863
8	.917	.050	.158	−.170	−.180	.930
9	.736	−.395	−.140	.041	−.155	.743
10	.745	−.269	−.176	−.332	.207	.811
11	.894	.231	−.134	.067	.062	.879
12	.857	.155	−.223	−.275	−.058	.887
13	.886	.095	−.114	−.217	−.150	.877
14	.809	−.107	.293	.143	−.168	.873
15	.827	.147	−.276	.170	−.174	.841
16	.687	−.380	−.099	.368	−.114	.775
17	.768	−.391	.150	−.231	.197	.857

TABLE 5

Transformation Matrix

	A	B	C	D
I	.168	.212	.191	.925
II	−.833	.040	−.453	.304
III	−.316	.975	−.099	−.216
IV	.422	.040	−.865	.069

TABLE 6

Rotated Factorial Matrix

	A	B	C	D	E
1	−.055	.138	−.059	.858	.272
2	.203	−.030	.095	.887	.041
3	−.051	.247	−.083	.904	.163
4	.019	.465	−.052	.754	.072
5	.088	.460	.008	.790	.032
6	−.056	.229	.313	.824	−.064
7	.045	.430	.068	.794	−.069
8	−.010	.344	.284	.818	−.180
9	.514	.006	.298	.594	−.155
10	.265	−.038	.569	.622	.207
11	.029	.071	.022	.931	.062
12	−.031	−.041	.354	.869	−.058
13	.014	.072	.325	.858	−.150
14	.192	.459	.051	.662	−.168
15	.176	−.081	−.029	.881	−.174
16	.619	.049	−.005	.567	−.114
17	.310	.284	.509	.543	.197

TABLE 7

Correlations between Primary Traits

	A	B	C	D
A	1.000	.283	−.047	.000
B	.283	1.000	.092	.000
C	−.047	.092	1.001	.000
D	.000	.000	.000	1.000

Attention is called to the column in Table 4 which is called 'h^2.' This column represents the communality, *i.e.*, that part of the variance of the given test which is due to factors common to other tests in the battery. The reliability of the tests, which is equal to, or greater than, the communality, is high. The variance due to specificity or to error and not accounted for in the extracted factors is correspondingly small.

Table 5, the rotated factorial matrix, contains five columns. Each column is interpreted separately.

Column D contains no zero or near zero projections. The smallest projections are for Tests 9, 10, 16, and 17, which are the tests of Memory for Commissions and Sentences scored in the two different ways. But even these loadings are fairly high, the lowest being .34. This column represents a general factor. From the nature of the battery it would seem that this factor is the memory span factor.

In Column C the entries to be considered are for the following tests:

Number of Test	Name of Test	Factor Loading
10	Sentences (scored for whole)	.569
17	Sentences (scored for parts)	.509
12	Concrete Words (oral)	.354
13	Abstract Words (oral)	.325
6	Concrete Words (visual)	.313
9(?)	Memory for Commissions (whole)	.298
8(?)	Abstract Words (visual)	.284

All of the tests with significant entries in Column C involve words. The tests with the highest loadings (Sentences) certainly involve ideas and words and relationships between words. It is also very possible that the subjects formed relationships or associations even between the discrete abstract and concrete words in an effort to retain them. Accordingly, it is suggested that the factor involved is Thurstone's verbal factor. It should be noted that the battery of tests was not sufficiently large or varied in nature to allow for unquestionable naming or interpreting of the factors. Any suggestions, therefore, in regard to the nature of the factors are highly tentative. These hypotheses or suggestions can be subjected to experimental check-up by including the tests in question in a battery with other tests that are known to be highly saturated with the factor or factors under consideration.

In Column B the entries to be considered are for the following tests:

Number of Test	Name of Test	Factor Loading
4	Geometrical Designs	.465
5	Colors	.460
14	Nonsense Syllables (parts)	.459
7	Paired Associates (whole)	.430
8	Abstract Words (visual)	.344
17(?)	Sentences (parts)	.284

The last one or two factor loadings are rather small, and hence their significance is questionable. It is evident that a factor of visual or spatial imagery may be involved in the tests of Geometrical Designs and Colors. But it is more difficult to explain why it is present in some of the word tests and not in others. However, as indicated before, the nature of the factor may be more readily determined by another experiment with more significant tests added to the battery.

In Column A the entries to be considered are for the following tests:

Number of Test	Name of Test	Factor Loading
16	Memory for Commissions (parts)	.619
9	Memory for Commissions (whole)	.514
17	Sentences (parts)	.310
10(?)	Sentences (whole)	.265

One way in which the above tests differ from the others is that they involve rapid reading and grasping of a complete idea. The factor may be some sort of a speed factor—possibly speed of reading or speed of apprehension. But, as before, the interpretation is tentative and the only concrete suggestion that may be made is that reading speed tests of several types be added to the present battery to test for the above mentioned factor.

The entries in Column E, the residual plane, are too small to be significant, and no special interpretation is necessary.

One other point of interest in the rotated factorial matrix is the comparative factor loadings of the visual and oral tests. These data are summarized in the table below.

Test	Factor Loading			
	A	B	C	D
Consonants (visual)	−.051	.247	−.083	.904
Consonants (oral)	.029	.071	.022	.931
Concrete Words (visual)	−.056	.229	.313	.824
Concrete Words (oral)	−.031	−.041	.354	.869
Abstract Words (visual)	−.010	.344	.284	.818
Abstract Words (oral)	.014	.072	.325	.858

In general, the factor loadings do not differ significantly for the two methods of presentation. In only one case is the

difference as high as .27. These results lean toward the view that the same factors are involved in auditory and visual memory span and to about the same degree. It is a question, however, how far we may generalize for materials other than the three reported in this study.

On the whole, the factorial analysis has borne out the conclusions drawn on the basis of the earlier statistical analysis. It was suggested before that the battery had a factor common to all of the tests. Factors A, B, and C are common only to certain ones.

Summary

Following is a summary of the conclusions drawn from the investigation described in the foregoing pages.

1. The listing of the materials in terms of increasing difficulty is as follows: Digits, Consonants and Colors (the latter two of about equal difficulty), Concrete Words, Geometrical Designs, and Abstract Words (the latter three of about equal difficulty), Paired Associates, Nonsense Syllables, Memory for Commissions, and Sentences.

2. The position of the individual in relation to the rest of the group is affected by two things—the presence of an ability common to all of the tests, and the presence of certain abilities common only to special groups of tests. The effect of the common factor is to tend to stabilize the position of the individual. The effect of the other several factors is to make the position of the individual fluctuate in relation to the other members of the group.

3. The general factor is tentatively described as the memory span factor. The other factors are not so readily recognizable as the first. The suggestion is made that one of the other factors may be Thurstone's verbal factor. In the case of the other two factors it is suggested that several kinds of tests of visual imagery and several kinds of tests of reading speed be included in a subsequent battery as a possible means of identifying the other two factors. In all cases, however, it should be clearly noted that the naming or describing of the factors is highly tentative and is intended only as a suggestion of further possible experimental study.

4. In the case of the three tests presented visually and orally the two methods of presentation seem to involve the same factors to the same degree.

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THE RELATIVE IMPORTANCE OF INTERVENING ACTIVITY AND LAPSE OF TIME IN THE PRODUCTION OF FORGETTING

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Historical Introduction [1]

At one time Thorndike (26) wrote, "when a modifiable connection is not made between a situation and a response during a length of time, that connection's strength is decreased." The implication is that disuse, in and of itself, produces forgetting. This raises the question as to whether the disuse which accompanies lapse of time is effective in causing loss of retention.

It was Ebbinghaus (3) who first dealt experimentally with the problem of loss of retention during increasingly longer lapses of time. He found that forgetting is a function of time, but this does not indicate whether it is mere lapse of time, or the interference of larger amounts of interpolated activity occurring during progressively longer periods of time. There was no attempt to separate the factors of intervening activity and lapse of time. In the classical curve of retention which Ebbinghaus obtained and in the curves of Radossawljewitsch (21), Finkenbinder (4), and Luh (15), there is an empirical determination of the loss which occurred after different intervals of time but no possibility of determining the major factor in the production of forgetting. As time increased, presumably, the total amount or duration of intervening activity rose in proportion. There is in these studies, however, no adequate control of the things which the subject or subjects did during the interim between learning and recall nor of the number of units, kind, or difficulty of the intervening activity in which they were engaged.

In 1924 Jenkins and Dallenbach (12) compared the rate of forgetting during sleep and waking. The results showed a slower rate of forgetting during sleep and a progressively larger difference between sleep and waking with longer periods of time. They concluded, as a result of their study, "forgetting is not so much a matter of the decay of old impressions and associations as it is a matter of the interference, inhibition, or obliteration of the old by the new." VanOrmer's (28) study showed similar results.

Gates (7) refers to disuse as 'a passive state' and seems to regard it as the primary factor in forgetting. Woodworth (30) says, "the machinery developed in the process of learning is subject to the wasting effects of time." He indicates that an act is forgotten when its brain condition has disappeared through long disuse. This places the influence of disuse in the nervous system. The latter statement is, however, merely an inference and is not subject to experimental test at the present time. Lashley (14) points out some evidence against one of the notions which might be suggested as a neurological basis of the above inference, *i.e.*, the theory of a resistance factor at

[1] The experimental work for this thesis was done under the capable supervision of Dr. A. G. Bills, now at the University of Cincinnati.

the synapse. Hunter (10), on the other hand, has recently said, "the loss of retention varies with the lapse of time; but, as the lapse of time increases, the quantity of interpolated activity also increases. It is to this latter factor that we must look for the explanation of the loss."

Chappell (1) has said that the forgetting function is only one of a large group of physical phenomena, all of which follow a logarithmic form because they obey the physical law governing the rate of dissipation of stored energy. Learning is compared to the storing of energy and forgetting to its dissipation. This theory seems to suggest that the physical or physiological processes which accompany mere lapse of time are very important.

Purdy (20) reports a case of a complete and isolated defect of immediate memory which was described by Störring. This condition was caused by gas poisoning which had presumably produced some organic change in the brain tissue so that there was a loss of ability to retain any fresh impressions. Purdy suggests that forgetting is due to the interaction between new and old traces.

Many experimenters, including Robinson (22), Skaggs (25), Cheng (2), Harden (9), McGeoch (16), and McGeoch and McDonald (19), have demonstrated that loss of retention varies with the degree of similarity between the kind of material in the original and interpolated activities, *e.g.*, similar material is more effective than dissimilar in producing a loss in the original learning. Johnson (13) found that similarity of meaning is a determining factor, and Waters and Peel (29) report that similarity in the form of the interpolated learning causes increased amounts of retroactive inhibition. As McGeoch (19) has indicated, however, these experiments on retroactive inhibition do not prove that disuse, or lapse of time, is utterly ineffective. They do prove that interpolated activity constitutes one causative factor.

McGeoch (18) writes, "to say that mere disuse, time unfilled for the acquisitions in question, will account for forgetting is, even were the correlation perfect, to enunciate a proposition too general to be meaningful. Time, in and of itself, does nothing." He holds that the significance of disuse is simply that it allows 'other and more specific factors' to operate, *i.e.*, 'retroactive inhibition and altered stimulating conditions.' He suggests that forgetting is an active interference by interpolated events. There is a need, however, for an experimental test of the hypothesis that the lapse of time is ineffective in producing forgetting.

The theories regarding the production of forgetting seem to fall under two heads: (1) those that emphasize some neurological process which necessitates only lapse of time in order to operate, and (2) those that suggest processes in which such psychological factors as kind and amount of intervening activity are prominent. It is, of course, impossible to set up an experimental condition in which there is no intervening activity in a lapse of time but we can make the amount small, the degree of difficulty simple, and the kind dissimilar. The rest activity which was used in the present study is an attempt to approach the minimum mental activity possible in the waking state. As compared with the piling up of the number

of units of difficult interpolated mental work, similar to the original learning task, this rest activity has very little interfering effect. It should, therefore, give more opportunity for any possible processes which take place in mere lapse of time to show their effect on retention.

What is the effect of increasing the amount, *i.e.*, the number of units of interpolated mental work, while holding the time constant? A unit of interpolated work is here defined as ten presentations of a nonsense list, similar in kind and difficulty to the original learned list, during which the subject makes his highest possible score in correct anticipations. It is easy to increase the number of units of interpolated activity by simply using additional lists. This method makes possible the determination of an experimental curve which shows the percentage of retention after successive increases in the number of units of interpolated activity while holding time constant.

It is necessary to obtain a control curve with which to compare the above experimental curve. Since the lapse of time and the duration or amount of intervening activity do vary concomitantly in actual life, and since they did vary, without control of the latter factor, in the curves of Ebbinghaus, Radossawljewitsch, Finkenbinder, and Luh, it seemed best to have a controlled variation of both factors. This was accomplished by using an additional unit of time, thirty minutes in this case, along with each increase in the number of units of interpolated mental work. All subjects engaged in the controlled rest activity during the time when there was no interpolated mental work. Corresponding points of the two curves are alike in number of units of interpolated activity but different in lapse of time between learning and recall and relearning.

Problem

To compare the curve of retention when time is constant and the number of units of interpolated mental work, similar to the original learning task, is varied with a control curve in which units of lapse of time and of intervening activity are varied concomitantly. In other words, this is an experimental

attempt to determine whether the loss of retention between learning and recall is a function chiefly of the amount, number of units, of interpolated activity or of the minimum processes accompanying mere lapse of time.

Apparatus and Materials.—(1) An electrically driven memory drum which presented each of the syllables in a series two seconds and made one revolution in thirty seconds was used to expose the material.

(2) Original and interpolated learning materials. One of the series of eight nonsense syllables was used for the original learning list with the remaining lists being available for interpolated material:

(1) meq, xid, juh, yop, tev, sij, fub, gax; (2) jid, ceh, zuk, paf, gix, kez, xul, qas; (3) mib, dax, huc, gef, kiv, laj, vuh, yoz; (4) zeh, jul, goq, xal, keb, qif, noj, yav; (5) kih, mec, zas, yom, vuk, cij, nax, foq; (6) bep, vaf, yud, koj, seb, xih, juc, tov.

(3) Final practice and ability test material. One of the following series was used with each subject in the final practice session and the other two were used for the ability test which was given before the subjects were divided into equated groups:

(1) cej, zir, juc, qas, veh, gik, yox, nub; (2) rix, guc, qov, xad, vej, yub, zom, nah; (3) daq, gic, juh, xeg, kaj, mif, zob, cex.

(4) Rest material. A game of chance was devised by the experimenter for this particular purpose. It is composed of a board having four lanes of spaces along which four different colored blocks can be moved. There are four dice which correspond in color to the blocks and a glass in which to shake them. Figure 1 shows the plan of the board on which the blocks were moved, following each throw of the dice.

(5) A stop watch was used for timing rest periods and score sheets for keeping records.

Selection of Nonsense Material.—From Glaze's (8) three lower lists the experimenter made up nine lists of eight each according to the rules which Luh (15) followed. These principles had been borrowed chiefly from Müller. These rules are as follows:

(1) All the initial and final consonants of the same series are different. (2) No two of four consecutive syllables have the same vowel (five vowels are used). (3) No two consecutive syllables have any consonant in common. (4) No group of consecutive syllables constitutes a polysyllabic word or phrase.

One of the problems in planning the experiment was to decide how many syllables to use in each list. Since the amounts of intervening activity which could be put into a rather short period of time would be limited, and because of the smallness of the lapses of time, it was thought best to use a fairly short list so as to allow more chance for interference with retention. This idea is in line with Robinson's (23) demonstration that longer lists are better integrated than shorter ones, probably because they receive a greater amount of overlearning.

It appears that the degree of integration after the original list was completely learned was sensitive enough to loss of retention under the conditions of this experiment. The experimenter was in doubt about this matter before obtaining the results since McGeoch (17) had used only eleven presentations of the original list for all subjects in one of his studies, and several others had used some constant number of presentations for their work on retroactive inhibition. It seemed best in this study, however, to have the original list learned so that there would be a one hundred percent starting point for the experimental and control curves. In this way they would be more in line

with the curves of retention of Ebbinghaus and others. The writer is of the opinion that longer lists would be less desirable for an experiment of this sort. There is also the possibility that very much shorter lists would be less suitable. Both of these

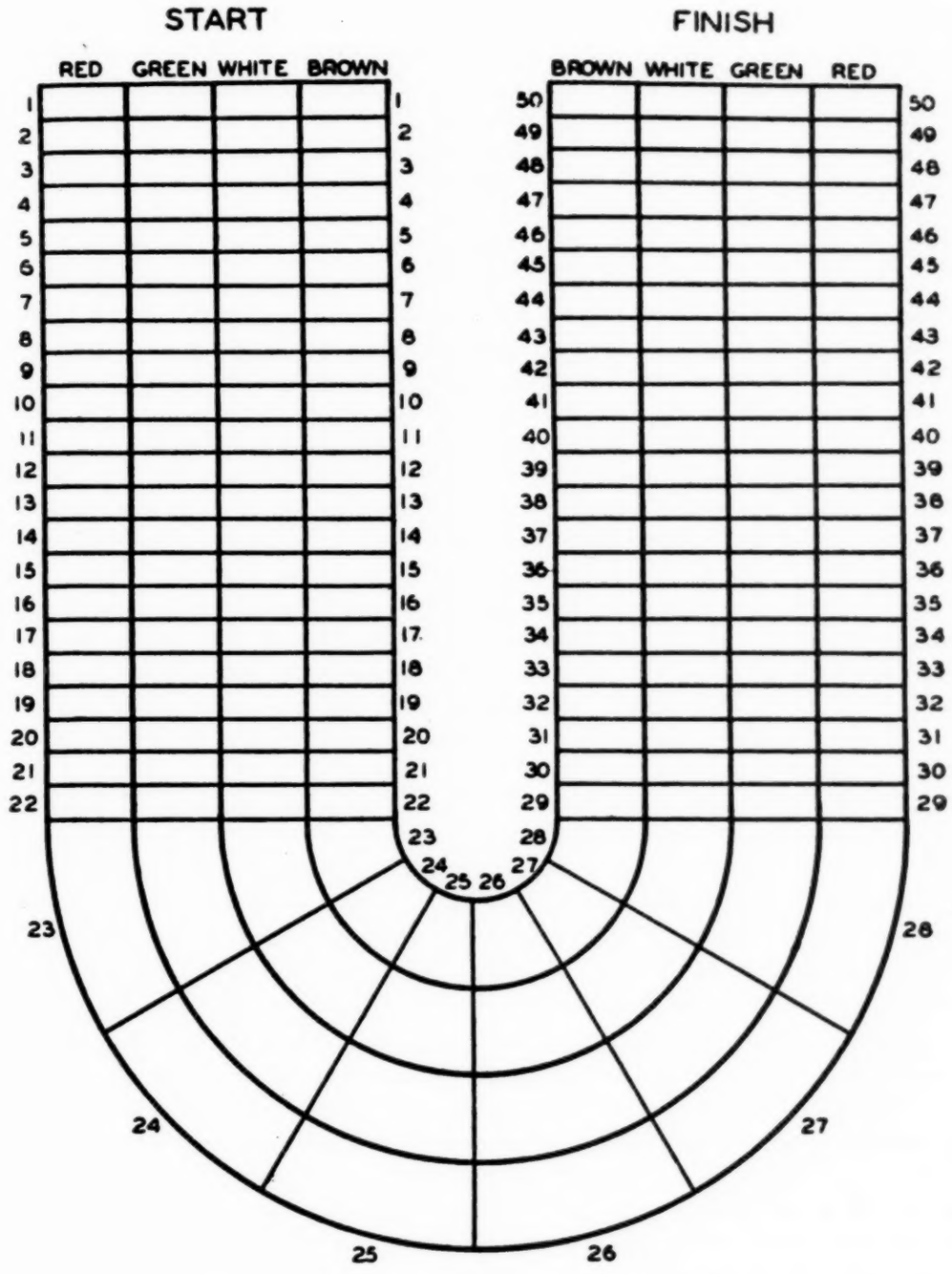

FIG. 1. Plan of board used in the rest activity.

statements seem to be in line with the findings of Robinson and Heron (24). They found a general tendency toward decreasing susceptibility to inhibition with increasing length but a striking exception in certain cases of material of shortest length, *i.e.*, six syllables.

Selection and Training of Subjects.—All subjects were junior college students of approximately the same age who had had or were taking the course in General Psychology.

Preliminary training in group conditions consisted of the following procedures: The experimenter printed on pieces of cardboard a series of one syllable nouns and a series of nonsense syllables. He stood at the front of the room and showed each card in turn through the given series. The subjects would write, on prepared sheets in the proper place, the syllable coming up next. After a given presentation of a series each subject pushed a book over his previous work and was ready for the next presentation. This preliminary practice was done in classroom groups. No account of the results was taken since the purpose was simply to acquaint the prospective subjects with the kind of material and the general procedure in the anticipation method of learning.

After the preliminary practice in groups each of the one hundred sixty prospective subjects had three individual practice sessions with the apparatus and kind of learning conditions which were used in the present experiment. At the third sitting, after the final practice, two of the series under (2) in 'apparatus and materials' were learned to one perfect anticipation and the average number of trials was computed. These ability scores were used to throw the subjects into nine equated groups.

Since the above ability scores were obtained after the subjects had had considerable practice it was assumed that they had reached their best rate of learning, under these conditions, and that practice effects would not bother in the main experiment. The subjects were thrown into nine groups with fifteen in each one, in such a way as to make the mean and the mean deviation of the nine different distributions approximately the same. Since it was possible to reject twenty-five of the prospective subjects this distribution of one hundred thirty-five scores into nine equated groups proved to be fairly easy. These nine equated groups were designated as follows: A, B, C, D, and E, the experimental groups, and S, T, U, and V, the groups to be used in the control conditions.

Procedure.—Technique: Subjects in the experimental groups, A, B, C, D, and E, learned the original list by the anticipation method to a criterion of one perfect trial. Thirty minutes later they were tested on anticipatory recall and the number of trials to relearn. For interpolated activity the subjects were given from one to five lists, with ten presentations each, according to the group in which they had been placed. Subjects in the control groups, S, T, U, and V, were given from two to five interpolated lists in periods of time which were increased by thirty minutes for group S and by an additional thirty minutes for each succeeding group. Thus, the period of time between original learning and recall for group V was two and one-half hours.

The period of time required for the interpolated lists always came in the middle of the lapse of time between the completion of the original learning and the beginning of recall and relearning. This was true in both the experimental and control conditions. When not working on the interpolated lists each subject, in both the experimental and control conditions, was engaged in the rest activity which was playing a simple game of chance with the experimenter. Careful study of the procedure will show that group A may be considered as belonging with the control groups or with the experimental groups, depending upon the point of view. One can see, from the above description, that the conditions for the following pairs of groups, B and S, C and T, D and U, E and V, are alike in number of units of interpolated mental activity but different in lapse of time between original learning and recall and relearning. This is more easily apparent in Tables 1 and 2.

TABLE 1

CONDITIONS FOR EXPERIMENTAL GROUPS BETWEEN ORIGINAL LEARNING AND RECALL AND RELEARNING*

Group	Rest Activity	Interpolated Work	Rest Activity
A	12½ min.	5 min. (1 list)	12½ min.
B	10 "	10 " (2 lists)	10 "
C	7½ "	15 " (3 lists)	7½ "
D	5 "	20 " (4 lists)	5 "
E	2½ "	25 " (5 lists)	2½ "

* Total time between learning and recall in each of above is 30 min.

TABLE 2

CONDITIONS FOR CONTROL GROUPS BETWEEN ORIGINAL LEARNING AND RECALL AND RELEARNING*

Group	Rest Activity	Interpolated Work	Rest Activity
A	12½ min.	5 min. (1 list)	12½ min.
S	25 "	10 " (2 lists)	25 "
T	37½ "	15 " (3 lists)	37½ "
U	50 "	20 " (4 lists)	50 "
V	62½ "	25 " (5 lists)	62½ "

* Total time between learning and recall was 30 minutes for group A, and was increased by the same amount in each of succeeding groups.

Directions to Subjects: (1) Directions for Learning the Original List in the Experiment Proper and for the Practice Sessions. "I have a series of eight nonsense syllables each one of which will be exposed for two seconds. Your problem is to learn to anticipate by spelling each syllable just before it appears. Each syllable should be regarded as the stimulus for responding immediately by spelling the following syllable. You will gradually approach this result. There will be five blank spaces between successive presentations, followed by the letter 'a' appearing twice to give you a sufficient cue for beginning the series. The second time the letter appears is the stimulus for spelling the first syllable."

(2) Directions for Rest Activity. "Here is a game which we are to play in order to see how chance works. We will take turns throwing these dice of four colors out of this glass and then move the four blocks of corresponding colors along their lanes as many spaces as the numbers on the dice. You move the brown and white blocks and I will move the red and green ones. Let's just relax and enjoy ourselves and our record, just now, along with many others will show how chance behaves under these conditions."

(3) Directions for Interpolated Activity. "You are to follow the same method that you did in learning the first series except there will be ten presentations only. You should strive to make as many correct anticipations as you possibly can during these presentations. I will keep a record of the number you are able to make."

(4) Directions for Anticipation Recall and Relearning. "This series is the first list which you learned. Be sure to anticipate as many as possible on the first presentation and then continue to relearn them until you can anticipate each one correctly again."

Minimizing Other Variables: (1) Affective Attitude. The experimenter impressed upon the subjects the idea that the purpose of the experimental method is not to prove something but to set up conditions so that nature will have to give an answer to a question, one way or the other. Either answer is of equal importance to science. Each subject was instructed, therefore, to be unconcerned about the results and just to follow all instructions to the best of his ability. During the first two individual sittings of the practice sessions the subjects were helped to become thoroughly accustomed to the procedure so as to minimize the effect of affective attitude.

(2) Suggestion. Each subject was used only once in the main experiment so he did not know what to expect and was unable to form some hypothesis which he might attempt to test out at the next sitting. This is assuming that there was complete coöperation in the matter of discussing the experiment with no one. After a subject had served in the main experiment he was told that the experimenter is interested in observing the variations among subjects in learning and relearning nonsense syllables, at different intervals, and also in the way chance will behave, where many subjects are involved, in a game of this kind. This seemed to satisfy the subject's curiosity and to help him dismiss it from mind. He was told that to be able to keep the conditions of the experiment entirely to himself, until it had been completed, was a measure of maturity. Finally, the experimenter reminded him, just before his departure, that each subject is asked if he has heard of any previous subject's experience.

(3) Diurnal Variations in Efficiency. An example of the influence of this variable is Tolman's (27) study in which he compared the amount of inhibition of interpolated work on lists of nonsense syllables learned in the morning with similar lists which were learned in the afternoon and in the evening. He found that retroactive inhibition was greater for the afternoon and evening lists. In the present study one-third of the subjects from each group was used during each of the three parts of the day, *i.e.*, morning, afternoon, and evening. This was done with both the experimental and control groups.

(4) Order of Subjects from the Different Groups and Within Each Group. Subjects were used from the different groups in a thoroughly mixed manner and, in such a way, that at any time during the experimental period practically the same number of subjects had been taken from each of the nine groups. The experimental schedule was also set up so that there was alternation from good to poor learners, under these conditions, within each of the groups.

(5) Interference from Rest Activity. In preliminary tests with a few subjects this rest activity was followed by a smaller loss in retention than resulted from reading and marking the best joke in a given series. The game was devised in order to provide sufficient interest so that the subject might sustain his attention to the matter at hand and, at the same time, make it possible to encourage considerable relaxation. Because of its simplicity and the amount of reliance on motor manipulation this game seems to require a minimum of mental activity. The small amount of mental activity involved is very different from the kind in which the subject engaged during the original learning task.

(6) Order of Using Nonsense Lists. In the main experiment a different list, of the six on the memory drum, was used as the original series with each succeeding subject. This original list was always preceded by the same cue, however, which was the letter 'a' appearing twice. The letter 'b' appeared twice before the first interpolated list, 'c' before the second, etc. This was made possible by preparing six pairs of the little cards, to be inserted and taken out, in the two spaces on the memory drum which came just before the nonsense lists. If the first pair was used, the A's were

above the list on the extreme left, with B's, C's, D's, etc., across to the right. With the second pair inserted the A's were moved one place to the right, with the third pair they were two over, etc. This made it possible for each succeeding subject to have the same cues but a different arrangement of lists. In this way, also, there was always a period of two days or more before any subject would again have the same arrangement of lists.

(7) Degree of Interpolated Learning for Different Groups. As already pointed out, under 'Technique,' each interpolated list was presented ten times. In addition to this, as noted under 'directions to subjects,' there was an attempt to induce in each subject a high degree of motivation to make the best record possible, in correct anticipations, during the period of ten presentations. That the amount of effort in the different groups was quite similar can be seen by noting Table 3. The average of the number of correct anticipations on the different interpolated lists was determined for each subject, except for those in group A where there was only one interpolated list. The distribution of these subject averages in the different groups was then considered and the mean and mean deviation were determined for each group. These results are what is shown in Table 3.

TABLE 3

DEGREE OF INTERPOLATED LEARNING FOR THE DIFFERENT GROUPS

Group	Mean	Mean Deviation
A	32.6	9.11
B	30.8	7.83
C	30.31	8.67
D	28.8	7.87
E	27.04	7.53
S	32.33	7.39
T	31.64	7.74
U	30.9	7.27
V	29.5	7.52

Note: The record of the number of correct anticipations during the ten presentations was obtained for each subject on all of the interpolated lists used with him. Thus, subjects in group A had one result (1 list), those in groups B and S two results, in groups C and T three, etc. For all groups other than A, the average of the correct anticipations on the different lists was determined for each subject. These subject averages were thrown into their proper group distributions and the mean and mean deviation were then determined, as shown in the above table.

Results.—Under 'minimizing other variables' (7) above, the experimenter described the method of equating the degree of interpolated learning for the different groups. It appears, from the results shown in Table 3, that there was practical equality in the degree of learning of the interpolated lists, so this factor is ruled out as an explanation of the findings in this experiment.

Did the groups which had been equated by means of the preliminary ability test, for learning under these conditions,

remain equated on the basis of the trials required for learning the original list? The answer to this question is shown in Table 4. Since the difficulty of the nonsense lists, used in

TABLE 4

COMPARISON OF AVERAGE NUMBER OF TRIALS IN ORIGINAL LEARNING WITH THE SAME IN THE PRELIMINARY ABILITY TEST

Group	Preliminary Ability Test		Original Learning	
	Mean	Mean Deviation	Mean	Mean Deviation
A	22.73	7.01	19.07	6.87
B	22.67	7.11	19.67	7.11
C	22.87	6.94	22.67	7.16
D	22.73	7.05	20.13	6.83
E	22.67	6.93	21.27	4.83
S	22.67	6.93	20.6	7.39
T	22.73	7.05	19.27	5.62
U	22.6	7.04	19.27	4.21
V	22.93	6.99	22.6	7.65

the preliminary test, was approximately the same as that of the lists in the main experiment it appears that there was a slight practice effect shown in the original learning results. With the exception, however, of the mean deviation in groups E, T, and U, the surprising thing is the closeness with which these results approximate those of the preliminary ability tests.

The average number of trials required to learn the original list, to relearn the same list after rest and interpolated activity, and the mean number of syllables recalled during the first presentation are shown in Table 5. A striking thing which should be noted in this table is the similarity in the mean number of trials for relearning in the paired groups B and S, C and T, D and U, and E and V. There are almost as large increases in the size of the means when only the number of interpolated lists is increased, during a constant period of time, as when additional units of time are also included. It should also be noted that the mean deviations increase along with the means which indicates more scatter in the distributions of relearning trials as the number of interpolated lists was increased.

TABLE 5

NUMBER OF TRIALS IN ORIGINAL LEARNING, IN RELEARNING AND NUMBER OF SYLLABLES RECALLED

Group *	Original Learning		Relearning		Syllables Recalled
	Mean	Mean Deviation	Mean	Mean Deviation	Mean
A	19.07	6.87	5.53	1.24	1.4
B	19.67	7.11	6.93	1.29	1.13
S	20.6	7.39	9.3	2.46	.8
C	22.67	7.16	9.74	2.55	.41
T	19.27	5.62	10.87	3.17	.2
D	20.13	6.83	11.33	2.61	.27
U	19.27	4.21	11.67	3.19	.13
E	21.27	4.83	13.53	4.24	.07
V	22.6	7.65	14.87	4.67	.13

* The experimental groups are A, B, C, D and E. The control groups are S, T, U and V.

It would have been possible to figure an average percentage retention score for each group by using the means for original learning and relearning. This would have made it impossible, however, to have percentage retention distributions as shown in Table 6 from which to determine whether or not the differences between the means of the paired experimental and control groups are significant. The writer found, also, that the first method, mentioned above, gave slightly different results than the one finally used.

The formula, $S = 1 - \frac{\text{trials to relearn}}{\text{trials to learn}} \times 100$, was used on the results for each of the subjects in all nine groups. This gave the distributions of the percentage retention based on the saving score in relearning that are shown in Table 6. The means of the groups A, B, C, D and E determine the Experimental Percentage Retention Curve and the means of the groups A, S, T, U and V mark the Control Percentage Retention Curve as shown in Fig. 2. It is apparent that they run progressively closer together. This figure shows one picture of the most important results in the present study.

TABLE 6

DISTRIBUTIONS OF THE PERCENTAGE RETENTION BASED ON THE SAVING SCORE IN RELEARNING OF THE FIFTEEN SUBJECTS IN EACH GROUP

A	B	S	C	T	D	U	E	V
.92	.79	.72	.78	.66	.75	.59	.67	.54
.83	.78	.70	.75	.62	.66	.56	.61	.52
.79	.75	.68	.69	.60	.65	.56	.59	.50
.77	.74	.64	.68	.54	.64	.52	.59	.43
.73	.73	.60	.68	.53	.61	.52	.48	.41
.71	.72	.54	.53	.50	.60	.52	.47	.39
.69	.67	.54	.52	.48	.54	.47	.46	.35
.68	.60	.53	.50	.47	.50	.44	.37	.31
.67	.58	.50	.48	.46	.32	.38	.35	.24
.67	.54	.45	.46	.35	.21	.33	.34	.23
.62	.50	.44	.44	.34	.18	.25	.20	.22
.58	.50	.40	.33	.28	.00	.21	.11	.20
.57	.44	.39	.33	.27	−.08	.18	.05	.18
.33	.20	.31	.20	.23	−.10	.15	−.05	.08
.12	.14	.00	.10	.09	−.27	−.09	−.29	−.17
M.*	M.	M.	M.	M.	M.	M.	M.	M.
.645	.578	.496	.499	.428	.347	.372	.331	.295
σ*	σ	σ	σ	σ	σ	σ	σ	σ
.191	.193	.177	.186	.157	.322	.189	.266	.181

* M.—Mean. σ—Standard Deviation.

Formua used on each subject's results, $S = 1 - \frac{\text{trials to relearn}}{\text{trials to learn}} \times 100$.

Since a recall score, other than zero, was absent in many of the individual subject cases, the percentage retention on this basis was computed from group means in number of syllables recalled as shown in the last column of Table 5. This average number of syllables recalled was divided by eight, the number of syllables in the original list, in order to obtain the percentage retention according to the recall criterion. These values determine the experimental and control curves shown in Fig. 3. These curves show a trend, also, toward coming progressively closer together.

The results of this study show that the percentage saving in relearning criterion was more sensitive than recall as a measure of retention. That is, there were many cases in which a considerable amount of retention was present when tested by the former standard although the latter scores were zero. It may be, however, that the recall criterion is equally valid in comparing the groups. Due to the fact that the noted

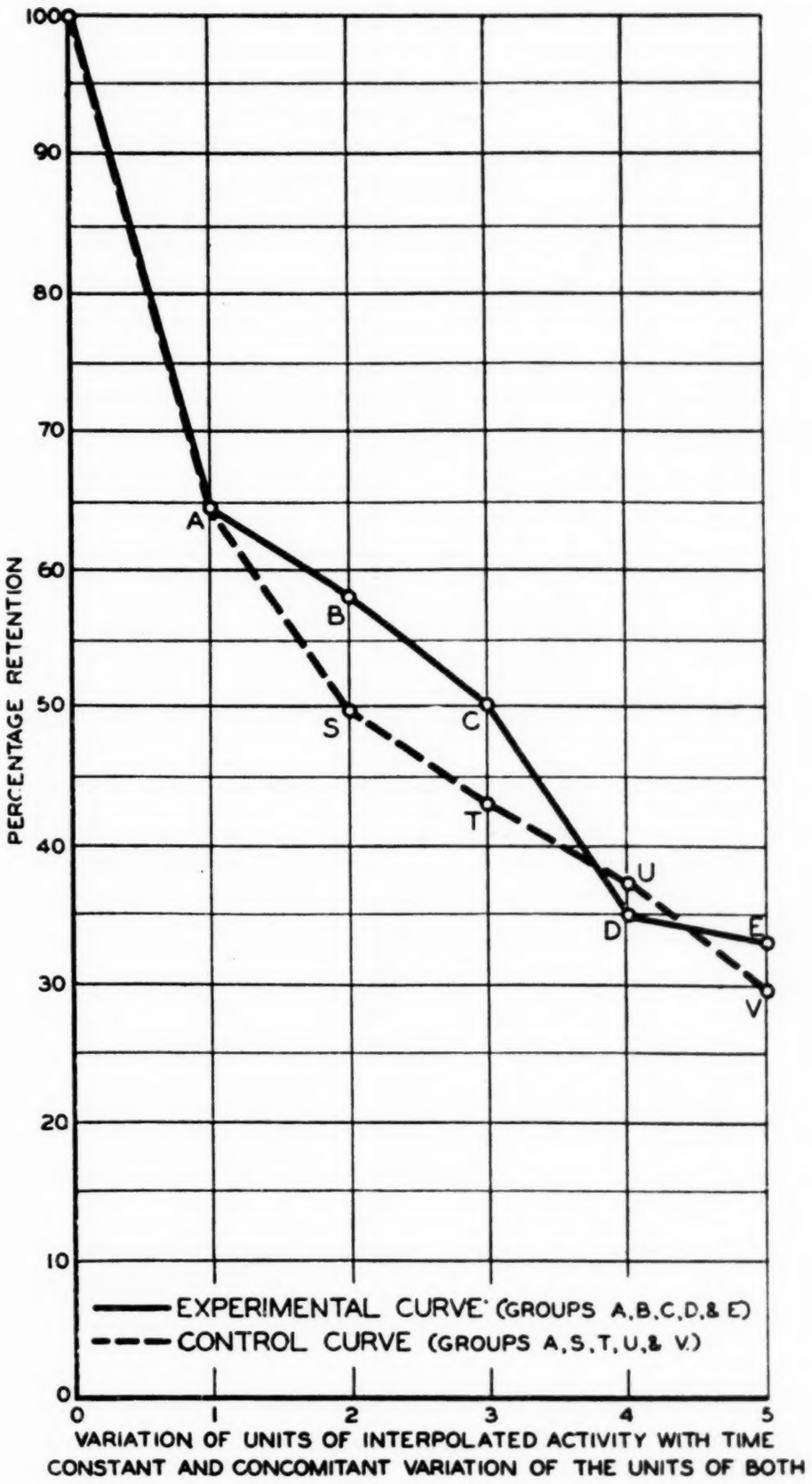

FIG. 2. Percentage retention curve (saving score in relearning).

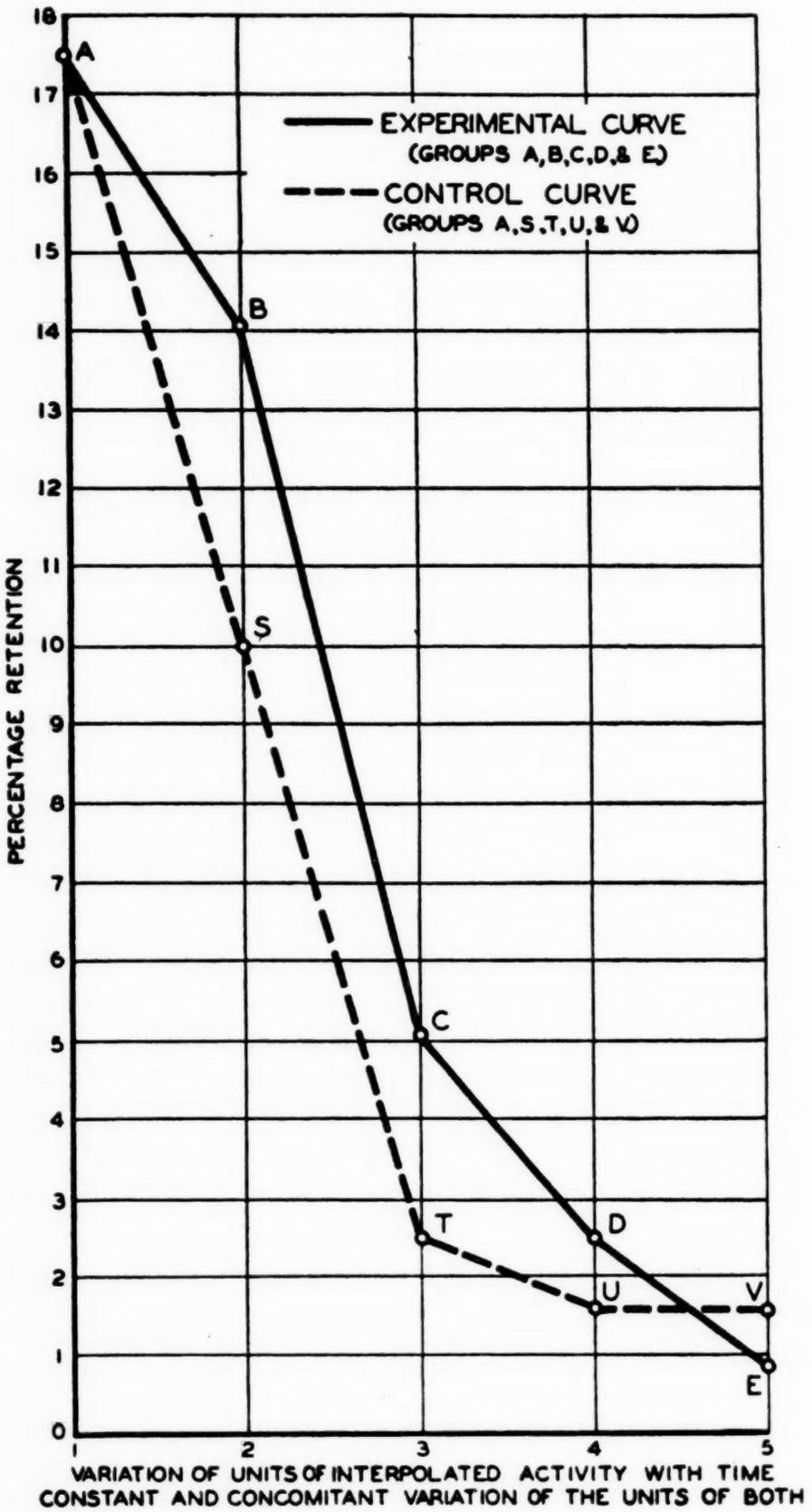

FIG. 3. Percentage retention curve (recall criterion).

curves of retention of Ebbinghaus and others show the percentage of retention based on the saving score in relearning this is the criterion which the writer aimed to emphasize in the present study.

The comparison of the pairs of groups, B and S, C and T, D and U, and E and V, which were similar in number of units of interpolated mental work but different in lapse of time, is the crucial point of this experimental study. Table 7 shows

TABLE 7

CRITICAL RATIOS OF CORRESPONDING EXPERIMENTAL AND CONTROL GROUPS

Group	Mean	σ * mean	Diff. of Means	σ * Diff.	Critical Ratio (Diff./σ * Diff.)
A	.645	.0493			
B	.578	.0498	.082	.0675	1.21
S	.496	.0457			
C	.499	.0498	.071	.0642	1.106
T	.428	.0405			
D	.347	.0831	.025	.0963	.257
U	.372	.0487			
E	.331	.0686	.036	.0827	.435
V	.295	.0463			

* σ—Standard Error.

the difference between the means, the standard error of this difference and the ratio of these two measures. These were computed from the percentage retention distributions shown in Table 6. It is important to note the size of these four critical ratios for it indicates that none of the differences between the pairs of means is statistically significant. The most important cue in the results, however, upon which to base a conclusion to the present problem is the fact that the critical ratios become progressively smaller as the lapses of time are increased in the control groups. Figure 2 also indicates, in an easily perceptible form, that the experimental and control percentage retention curves run gradually closer together as the lapses of time become greater in the control groups.

CONCLUSIONS

The results of the present study suggest the following tentative conclusions. They are applicable only, however, to the

conditions of this experiment. It must be remembered, for example, that the intervening mental activity was similar in kind and difficulty to the original learning task and also composed of different separate units. The periods of time concerned were, also, necessarily limited in length.

1. Increasing the amount, number of units of interpolated mental work during the same period of time, produces much the same percentage retention curve as is obtained when time is increased proportionally along with the enlarged amounts of intervening activity.

2. As the number of units of interpolated activity is increased, during the same period of time, the resulting percentage retention curve approaches more and more closely the control curve in which lapses of time were larger in proportion to the increased amounts of intervening mental work.

3. Loss in retention is a function chiefly of the amount, number of units, of interpolated mental work rather than of those minimum processes which accompany mere lapse of time. Thus, a major factor in the production of forgetting is the amount, number of units, of intervening mental activity and the minimum processes which accompany mere lapse of time are relatively ineffective.

4. When time is constant the amount of loss in retention varies directly with the amount of interpolated mental work.

The above conclusions seem to apply to both criteria used, *i.e.*, the percentage recall and the percentage retention according to the saving in relearning but the application to the latter is of more significance in this study.

Additional Findings

1. Groups which have been carefully equated in learning nonsense lists, after sufficient preliminary practice, will tend to remain equated in the learning of other lists. This conclusion is indicated by the results shown in Table 4.

2. The degree of learning during a given number of presentations of interpolated lists of nonsense syllables will approximate equality in groups already equated in nonsense learning ability. Results shown in Table 3 support this statement.

3. The criterion of percentage saved in relearning usually shows considerably more retention than does the percentage of recall.

4. This Control Percentage Retention Curve based on the saving scores is similar in shape to the famous curves of Ebbinghaus and others but the characteristic form is produced during a shorter period of time. Almost as much loss resulted during a period of two and one-half hours as Ebbinghaus obtained in two days. In the studies of Ebbinghaus, Radossawljewitsch, Finkenbinder and Luh there was no attempt to control the nature of the intervening activity in any definite manner but it was dissimilar to the original learning and much less difficult. In the present study, however, the interpolated work was of a highly retroactive sort and the increased units of it remained similar in kind and difficulty to the original learning.

Discussion and Interpretation

It should be noted that similarity in kind, degree of difficulty, and intensity of effort are not variables in this study. Only the amount, number of units in a given period of time, of the interpolated activity is varied in the experimental groups. There is, of course, a slight variation of the duration of the rest activity in these groups but the total time is short in each case. In the control groups lapse of time between original learning and recall and relearning is varied concomitantly with the amount of intervening mental work and in the same proportion. The duration of the rest activity, in these groups, varies considerably but in the opposite direction to the slight variation in the experimental groups.

Why is it possible to conclude that the minimum processes which accompany mere lapse of time are relatively ineffective in the production of forgetting? It is because of the relationship of the experimental and control curves of retention which can be noted in Fig. 2. If time were a major factor the curves should get progressively farther apart as the amount of time is increased in the successive control groups. The corresponding points of the two curves, on the contrary, get closer together. This is the crucial thing in the results of the present study which made possible a tentative answer to the experimental question being investigated.

No one should conclude that the results of the present study prove that the minimum processes which accompany mere lapse of time have no effect on retention but, rather, that they are relatively ineffective as compared with the influence of the number of units of interpolated mental work.

Why did time, amount or duration of the rest activity, appear slightly effective at first but less and less effective in the relationship of the latter parts of the curves? A possible hypothesis would be that as the number of units of intervening activity which is similar in kind and difficulty to an original difficult learning task is piled up, between learning and recall, it becomes relatively more and more important than those minimum processes which accompany mere lapse of time in producing a loss in reten-

tion. This principle may be so effective in its operation that it covers up the small effects of increasing the amount or duration of the rest activity during longer lapses of time.

There are other possible factors in explanation of the question stated at the first of the preceding paragraph. It is possible that with longer rest activity periods the threshold to such moderate stimulation became gradually higher so that there was a decreased amount of mental responding or activity, and consequently, lessened interference with retention per unit of time. Freeman (6) says that the threshold of cortical neurones varies with the level of functional activity. Ford (5) argues that the repeated use of similar patterned stimuli must reduce behavior to such a condition that specific interference is no longer present. It seems likely, therefore, that any activity which is thoroughly automatized calls for an absolute minimum of mental activity to carry it on, and that this change comes gradually as the task is repeated over and over.

Another possible hypothesis to account for the two curves approaching each other is that there may be a change in the effectiveness of the interpolated activity in the successive control conditions. The interpolated activity may be less effective as the time after learning and before relearning is increased. There seems to be no published experimental data which relates specifically to the question as it would concern the conditions of the present study. Robinson (23) found that it makes very little difference when the interpolated activity is introduced but his study covered periods of time of only twenty minutes. Skaggs (25) concluded that a more detrimental effect is produced when work is introduced immediately following original learning than after a rest interval but his total period of time between learning and relearning was only ten minutes. What little evidence relates to the question is thus conflicting. Other studies have considered whether interpolated activity is most effective when introduced before original learning, immediately after it or just prior to recall but these results are not related to the above hypothesis.

Another possible contributing factor in the answer to this question relates to the relationship of bodily tonus and degree of mental activity. Jacobson (11) found that a certain amount of tension is necessary before mental activity can occur and that decreasing the amount of bodily tonus lessens the possibility of mental activity. It is possible that there was decreased bodily tonus during the increasing lengths of rest activity which may have been accompanied by a still further lessening of the small intensity of mental activity. This latter effect would mean a gradual decrease in the amount of interference produced by the rest activity upon retention. It may be, therefore, that as a subject engaged for a longer time in the rest activity, he approached gradually nearer that condition which has been here referred to as the minimum processes accompanying mere lapse of time.

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PROACTIVE AND RETROACTIVE EFFECTS IN THE RECOGNITION OF FORM

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Numerous studies on retroactive inhibition have furnished us with detailed information on this phenomenon as it affects the reproduction of verbal material. Non-verbal material has not been studied as adequately, nor has retroactive inhibition been demonstrated as clearly in the case of recognition, probably due to the more effective reproduction in recognition. Proactive inhibition has been demonstrated so rarely that further studies on this phenomenon are required.

Foucault (**2**) makes a very clear distinction between what he calls 'inhibition externe' and 'inhibition interne.' In the first case rest or another task is interpolated between learning and recall; the second type is more concerned with inter-serial inhibitory effects during learning of the one task. In both types of inhibition he recognizes the presence of 'inhibition regressive' and 'inhibition progressive,' retroactive and proactive inhibition, according as the inhibitory material follows or precedes the material to be learned. He demonstrates the presence of all inhibition types for verbal material.

Gibson and Raffel (**3**) offer an interesting technique for the investigation of retroactive inhibitory effects in immediate reproduction of figures. The present study concerns itself with inhibitory effects ('inhibition interne') on the recognition of form, and uses a technique similar in many respects to that of Gibson and Raffel though it was developed independently of theirs. Throughout the paper the term inhibition is used in the broad sense of Foucault. It will be shown that while other factors, notably anticipation and similarity, do influence the recognition, there is a residual effect which is inhibitory in the more precise meaning of the term.

Subjects

A preliminary experiment using 26 adults was devised to standardize procedure, time of presentation and difficulty of material. The experiment proper, upon which the data and conclusions of this paper are based, had as subjects 47 college students, 29 women and 18 men.

Material

The figure patterns to be compared were drawn on 24 cards of white cardboard, 7 by 11 inches. On each card was a sequence of straight and curved lines forming a six element pattern in black outline. These cards were arranged in 72 series of 4 cards each, providing for 288 card exposures. In each series one card of the first three was identical with the fourth card, or standard, one card was similar to the standard and one card was dissimilar to it. By similarity of card is meant some minor change in one, two or three of the elements, such as substitution of straight line for curved line, or slight variation of the angle at which the lines lay. Dissimilar cards were markedly different from the standard, not only in the places of occurrence of the straight and curved lines, but chiefly in the sequence of the pattern. Objectively stated, similar cards had the same general sequence as the standard, and not more than three minor changes in the elements; dissimilar cards had a decided difference in sequence from the standard, and changes in at least four of the elements. Calling the card similar to the standard, S; the dissimilar card, D; and the correct or identical card, C, the following permutations of presentation of the first three cards are possible: SCD, CSD, DSC, DCS, CSD and SCD. The fourth card or standard is merely a duplicate of the card to be identified with it, and is not given an identifying letter. The six possible types or arrangements of cards in a series were mixed up in random order in the total presentation of 72 series, approximately the same number being devoted to each. Examples of the various types of series are given in Fig. 1.

Procedure

Preliminary experimentation had established that group presentation of large figures was about as effective as individual tachistoscopic presentation of smaller figures, since the two methods yielded a correlation of 0.87. Before the experiment proper the following instructions were given orally to the group.

"You are going to be shown a series of four cards, on each of which a pattern is drawn. You are to compare the first three cards with the fourth or standard. A card identical to the standard will appear in either the first, second or third positions in the series. Immediately after the removal of the last card of the series, mark down in the correct place on the scoring sheet given you, the number 1, 2 or 3, according to the position in which the identical card appears."

Two sample trials were then given to familiarize subjects with the procedure and the material used. Though no precaution was taken against copying, there was no evidence of it, and no difficulty was experienced in having subjects follow instructions, as subjects were all accustomed to carrying out psychological experiments.

At the conclusion of the experiment each subject was instructed to indicate on the reverse side of the sheet the method used in attempting to identify the correct card, classified according to the following list:

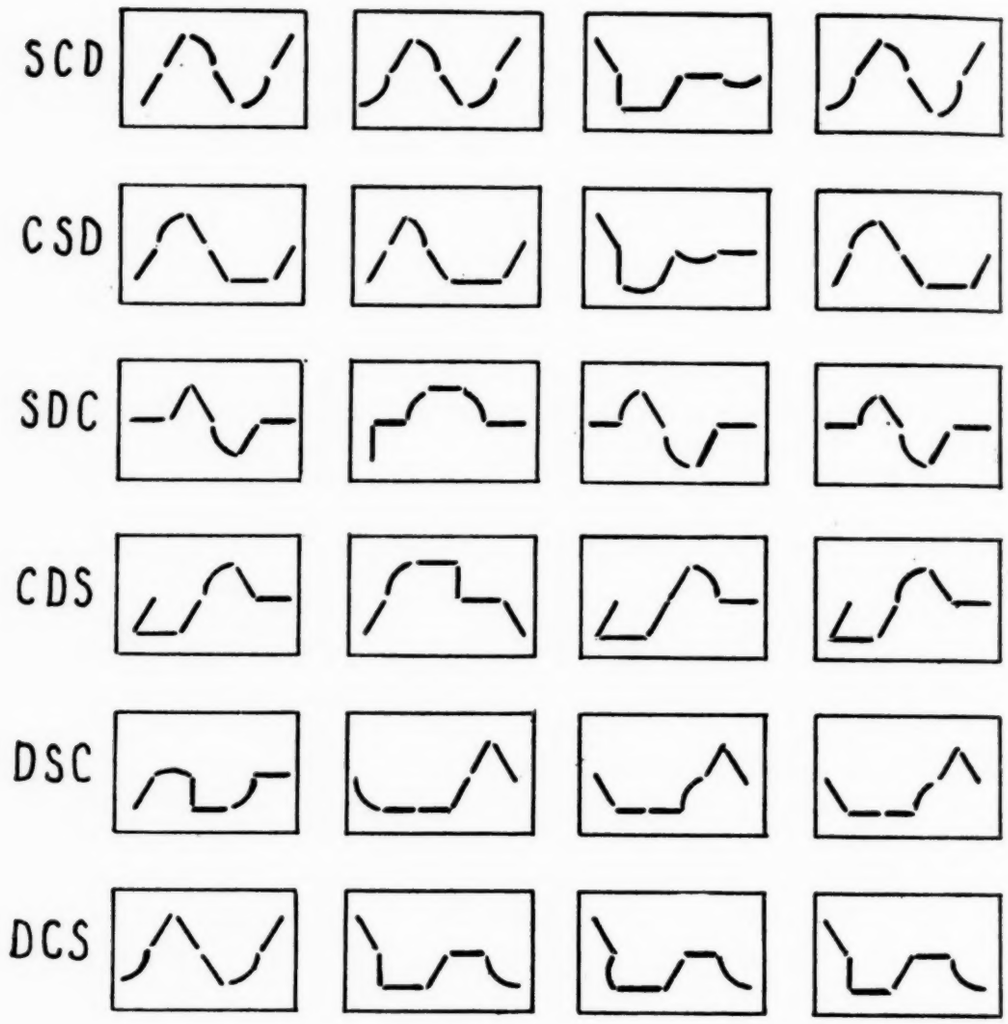

FIG. 1

(1) Number and position of the curved lines in the patterns.
(2) Vocalization.
(3) Motor procedures.
(4) Imagery.
(5) Any other specified method.

Each card of the series was exposed for five seconds; there was the briefest possible delay between exposures, and just time enough between series to record. Experimenters verified the fact that all subjects had completed their recording before the presentation of the next series, and a warning signal of 'Ready' was given before the start of every series. According as a series was about to appear, its numerical order was called out to facilitate correct recording.

RESULTS

Scoring presented no difficulty; the number of errors made by each subject on the 72 presentations was computed, and from this number the percentage of accuracy was determined. The average percentage score for 47 subjects was 87.2, which is

far too high to show the best effect of inhibition. However no correction was made for possibility of guessing; had this correction been applied it would naturally have decreased the score.

Learning was rapid at first, as may be seen from Table I, which gives the total errors per group of 6 series. Since errors

TABLE I

LEARNING, AS INDICATED BY THE TOTAL NUMBER OF ERRORS PER GROUP OF SIX SERIES ($N = 47$)

Group	1	2	3	4	5	6	7	8	9	10	11	12
Errors.....	89	41	43	42	48	27	39	22	28	18	22	20

were relatively frequent at the beginning of the learning series, obviously not sufficient pre-experimental practice was given. However when the scores of the first group of six series, from which point learning was fairly constant, were discarded, the general effects hereafter described were in no way altered; hence the entire 72 series was kept.

Despite the length of the experiment, and the references to fatigue made in the introspective reports, there was no marked diminution of efficiency towards the end of the task. In general the task was easy and initial learning was rapid, after which it was fairly constant. The reliability of the task as determined by the split-half method was 0.81 ± 0.03, which is probably a minimum figure as no care was taken to arrange the series in counterbalanced order to compensate for the varying difficulty of the six combination types.

Table II lists the frequency of choice of each type of figure, C, S or D, according to serial position. The six possible combinations permit figure types to occupy each serial position twice. When the frequencies of choice of each of these two possible positions are totalled the following facts are evident:

(*a*) Figure type C is chosen least frequently in position II; the frequencies of choice of C in positions I and III are equal.

(*b*) Figure type S is chosen least frequently in position I; the frequencies of choice of S in positions II and III are equal.

(*c*) Figure type D is chosen least frequently in position III; the frequencies of choice of D in positions I and II are equal.

TABLE II

PERCENT CHOICES ACCORDING TO POSITION ($N = 47$)

	Choice of Correct Figure, C		
	I	II	III
*C*SD	88.87		
*C*DS	85.32		
S*C*D		90.06	
D*C*S		81.67	
SD*C*			89.34
DS*C*			85.32
Average	87.10	85.87	87.33
	Choice of Similar Figure, S		
	I	II	III
*S*CD	7.98		
*S*DC	6.72		
C*S*D		9.49	
D*S*C		9.87	
CD*S*			7.24
DC*S*			11.96
Average	7.35	9.68	9.60
	Choice of Different Figure, D		
	I	II	III
*D*SC	4.85		
*D*CS	6.38		
S*D*C		3.93	
C*D*S		7.44	
SC*D*			1.96
CS*D*			1.64
Average	5.62	5.69	1.80

From (*a*) recognition of C obviously does not suffer a progressive deterioration according to the interpolation of increasing number of incorrect figures. The slightly inferior recognition of C in the middle position implies that retroactive inhibition is not alone operating, but that proactive inhibition also obtains; also that the effect of proactive and

retroactive inhibition is here approximately equal, for the recognition of C is equally good in positions I and III.[1] From (*c*) we infer that the proactive effect of D is greater than its retroactive effect and is equally inhibitive to recognition in positions I and II, where the frequency of choice of D is the same.

A tentative explanation for the variation in scores owing to the proactive and retroactive inhibitory effects on different types is here advanced, based on the following assumptions:

The presence of other figures in a series tends to inhibit the recognition of a determined figure. The inhibitory effect is called proactive when the disturbing figures precede the determined figure, and retroactive when they follow it.

The optimal position for any figure is that position in the series where its inhibitory effect, proactive and retroactive, on the recognition of C is at a minimum. The optimal positions are I and III for C, I for S, and III for D.

There is an additional inhibitory effect according as the figures are moved from these optimal positions. Let this additional inhibitory effect for C be x; for S be y, and for D be z.

Table III lists all possible combinations of the types of

TABLE III

ORDER OF DIFFICULTY OF COMBINATION TYPE

Type Position	Additional Inhibitory Effect			Percentage of Correct Recognitions
	I	II	III	
SCD.....	—	x	—	90.06
CSD.....	—	y	—	88.87
SDC.....	—	z	—	89.34
CDS.....	—	z	y	85.32
DSC.....	z	y	—	85.31
DCS.....	z	x	y	81.67

[1] Using three forms Gibson and Raffel (4) find the reproduction scores at the end of four seconds to be 4.0, 3.4 and 4.1 for the first, second and third positions respectively; and the respective scores at the end of eight seconds are 3.8, 3.6 and 3.9. The reproduction scores after twelve seconds do not show a minimum in the second position and an equality of the first and third positions. Foucault (2) likewise in his principal experiment finds scores of 98, 96 and 98 in the first, second and third positions respectively.

presentation, gives the additional inhibitory effect when the figure types are shifted from their optimal positions, and tabulates the average percent of correct responses per series for each combination type. The additional inhibitory effect is arrived at by a procedure which is best understood from examples. Thus in the combination CSD, figure types C and D are in their optimal positions, and S alone is displaced from its optimal position; hence y is the additional inhibitory effect. In the combination DSC, figure type C alone occurs in its optimal position; hence the additional inhibitory effect is $y + z$. Since the combination SCD yields the highest recognition we infer that the inhibitive effect due to displacing C from its optimal positions to position II is least. Since combination types CSD and SDC yield equal recognition scores, we infer that y and z, the inhibiting effects (proactive and retroactive) of shifting S and C from their optimal positions, are equal. The equality of CDS and DSC, and the position of DCS last on the list, fit in with this analysis of an equal inhibitory effect $y + z$ for CDS and DSC, and a maximum inhibitory effect $x + y + z$ for DCS. This explanation adequately accounts for the relative effectiveness of the various combination types for recognition, and in particular for the same scores made by the combination types CSD and SDC—and CDS and DSC.

The effects, x, y and z, are in general slight, being approximately of the order of 4 percent. However the conclusions found are probably reliable, for a tabulation similar to Table I for male and female subjects yielded exactly the same results. That tabulation is not presented here. Table IV, which pre-

TABLE IV

VARIABILITY OF THE RECOGNITION SCORES

Type	N	Mean	$\sigma_{Dist.}$	σ_M
SCD	12	42.33	2.60	0.75
CSD	13	41.77	3.16	0.87
SDC	13	41.99	4.30	1.19
CDS	10	40.10	4.96	1.57
DSC	11	40.09	5.06	1.52
DCS	13	38.38	5.57	1.54

sents data on the variability of the scores made on each combination type, shows that in spite of the small number of examples of each (not more than 13) the σ_M is relatively low. As a consequence of the small population, the inhibitory effects found are not statistically reliable, except for the largest difference found (SCD and DCS), the critical ratio for which is 3.80.

Discussion

The varying difficulty of the six combination types was not altogether unexpected, for several clues to the mental processes involved were gathered from a study of the statements made by subjects in regard to their method of recognizing the data. Thus a subject could work either from the beginning of a series of four figures, attempting to fixate all the figures, but probably stressing the first; or, on the other hand, he might quasi-passively survey the first three figures of the series, and then attempt to go back and recall which was the correct reproduction.

Should he work from the beginning, mental set or anticipation was a strong factor, occurring particularly in the case of the figure first presented. Subject definitely selected the first figure as a basis of comparison; if it happened to be the correct one then all was well and he was confident of his choice; if not, he tended to become confused and had hurriedly to revise his choice, attempting to decide which of the other two was correct. Most subjects learned to distrust this anticipation and changed their procedure to work from the end. On the other hand, should he work from the end, a direct comparison, particularly of the third figure with the standard, was the usual procedure. If the third figure, C, were correct, or if it were the different one, D, generally the task was very easy and no hesitation was felt.

The similarity and dissimilarity of the cards was both a hindrance and a help. The inhibitory effect was evidently enhanced by the similarity of the cards, but, on the other hand, definite cues were afforded by this factor to the correct recognition. Subjects were not told that one of the cards would

be similar, and the other dissimilar, to the standard, but they soon learnt to make good use of figure resemblances. Thus if two similar cards came at the beginning, one was sure to be right and subjects could afford to disregard the third card, concentrating merely on the standard. As a result very few mistakes were made on SCD and CSD.

Subjects who worked from the beginning tended to anticipate the standard, and since C occurred at the beginning only once on three times, more often they were wrong and had rapidly to revise their selection. Subjects who worked from the end generally looked closely for similarities so as to narrow the field of choice from three to two figures. As a consequence this method was easier and surer than working from the beginning.

In the construction of the figures use was made of straight and curved lines; 7 figures had one curve, 13 figures had two curves, 2 figures had three curves and 2 figures, four curves. Moreover the curve elements could appear at any of the six possible positions in the figure. Most subjects counted the number of the curves and attempted to memorize their location, a form of verbalization that possibly accounted in part for the high scores made, and tended to facilitate the detection of dissimilarities. As a consequence, learning was rapid.

Guessing, particularly when subject became confused, was of course present. Owing however to the high average score (87%) and to the confidence with which most choices were made, the usual correction for guessing in multiple choice questions was not used. In this paper we are more concerned with the presence of inhibitory effects than the accurate determination of scores. Naturally inhibitory effects would remain no matter how the scoring level was affected.

Of course, as has been pointed out, in addition to the factors of anticipation and similarity, proactive and retroactive inhibition due to serial position were also present. The recognition was influenced and the memory traces were distorted by the preceding and succeeding figures in a series.

On the basis of the foregoing we will attempt to analyze the relative difficulty of the various combination types.

SCD AND CSD

If subject worked from the end, D in both combination types was immediately perceived to be different from the standard; the choice then had only to be made between the first two figures. If subject worked from the beginning he perceived a similarity between the first two figures as they were presented and by this method also need only concern himself with them, to the exclusion of the third figure D. Type SCD involved the proactive effect of S and but a slight retroactive effect of D. An almost immediate comparison could be made between the second figure C and the standard, vitiated however in some cases by a tendency falsely to anticipate S, the first figure. As a consequence this combination type was the easiest of all. Type CSD had the retroactive effect of S and D. Anticipation in this case was a definite help, though as the test progressed it was used by fewer subjects. This combination type was one of the easiest.

SDC AND DSC

If subject worked from the end an immediate comparison could be made between C and the standard, influenced in both cases by the proactive effects of S and D. This proactive effect was greater when D was first since both figure types were then displaced from their optimal positions; hence SDC was easier than DSC. If subject worked from the beginning he noted the dissimilarity between the first two figures S and D, so that when C appeared he realized his choice lay between S and C, and consequently he was able to compare C with the following standard.

CDS AND DCS

Working from the end, subject had to wait till the third figure appeared till he saw that owing to the similarity of C and S his choice lay between them. Comparison with the standard was difficult as it was remote, particularly for CDS; hence retroactive inhibition was strong. The combined proactive and retroactive inhibition was also strong for DCS;—in fact each figure was in the most unfavorable position, and hence this order of presentation was the hardest of all.

Working from the beginning detection of similarities was delayed for both combination types. However if subject anticipated he would be correct in his choice of C, and confused and in error by his choice of D. For him also, therefore, type DCS was hardest of all.

Conclusion

Despite the inability of early experimenters (**5**, **12**) to find traces of inhibition when learning is tested by the recognition method, inhibitory effects in recognition have been found by Gibson (**4**), Lund (**8**), Gibson and Raffel (**3**), McKinney (**11**) and Zangwill (**14**) and their finding is here confirmed. The explanation advanced by Lund that experimenters who failed to detect inhibitory effects were working too far above the threshold or even within the recognition span, seems adequate, in some cases at least.

In addition to this general finding evidence is seen also in this experiment for the presence of conditions that determine the degree of inhibition to be found in recognition. Briefly some of these conditions are as follows:

The presence of a definite mental set or anticipation of retroactive influences tends to diminish inhibition. Cf. Lester (**6**) and Lumley (**7**).

This study does not confirm the finding of McKinney (**11**) that similar forms are more inhibitive than dissimilar forms. But serial position of similar forms is not an important factor for shorter lists, as McGeoch and Sisson (**10**) found when working with synonyms.

The complex of inhibitory influences which we may suppose to be at work among the items of a series of impressions is different in its total effect when the series bears the character of group membership. This finding of Gibson and Raffel (**3**) was also evident in the present experiment possibly on account of the close similarity of experimental conditions; the forms had to be designated for reproduction by serial position, in their case by E, and in ours, by S.

Proactive inhibition may have effects as important as those of retroactive inhibition, as was found by Crafts (**1**),

Foucault (**2**), Gibson and Raffel (**3**), Gibson (**4**), Melton (**9**) and Whitely (**13**). In the present experiment recognition seems to be affected to a strong degree by two other factors, peculiar to this experiment. A tendency to anticipation, which was pronounced for the first few series, was often the source of errors. Similarity of figure had the effect in some cases of limiting the choice between two positions, instead of three, when the dissimilar figure was seen. The presence of the dissimilar figure in such cases was more helpful than inhibitive. When due allowance is made for these factors, which are not ordinarily included under the heading of inhibition, there is definite evidence of the presence of proactive and retroactive inhibition, the meagreness of which is partly accountable for by the ease of the task.

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THE NEURAL TERMINATIONS RESPONDING TO STIMULATION OF PRESSURE AND VIBRATION

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Many years ago, Blix (1) discovered that the sensitivity for pressure was not uniform throughout the surface of the skin. Such sensitivity was found to be particularly concentrated near the roots of the hairs. In order to further investigate this problem, von Frey (9) invented the hair esthesiometer which is based upon the principle that there will be no further increase of pressure once the bending point of the hair has been reached. The adjustment of a series of hair esthesiometers with the hairs varying in thickness and in length makes experimentation in this field rather easy. It has been found necessary to adjust the hair with the greatest accuracy for, in this case, as shown in Fig. 1, the pressure will be relatively independent of the bending of the hair, while in the case of an already bent hair, the pressure will be partly dependent on the over-bending of the hair and hence becomes constant only in the case of great flexion.

If one end of the hair, as shown in Fig. 1, is strongly fixed while the other one is free and if r signifies the radius, l the length and E the mode of elasticity of the hair, we can develop the following equation for the limit of stiffness without bending:

$$P_{\max.} = \frac{\pi^3 E r^4}{2l^2}.$$

By changing the length of l one can thus change the maximal pressure in a way that is easily measured. For our relative measurements of pressure, therefore, we have used only one hair for stimulation. This is fastened in a small holder and the free length of the hair is measured after the determination of the threshold of the stimulus. As subsequent meas-

urements, carried out by means of small spring scales, have shown that it was always possible to find uniform hairs (obtained from violin bows) this enabled us to calculate the changes in the maximal pressure from the changes in length.

In order to examine the sensations of vibration in a small spot on the skin, the following apparatus was devised. A strong hair of about 1 cm in length was fastened on the vibrating part of a Creed-type electromagnetic loud-speaker system, care being taken, as far as possible, that the hair should

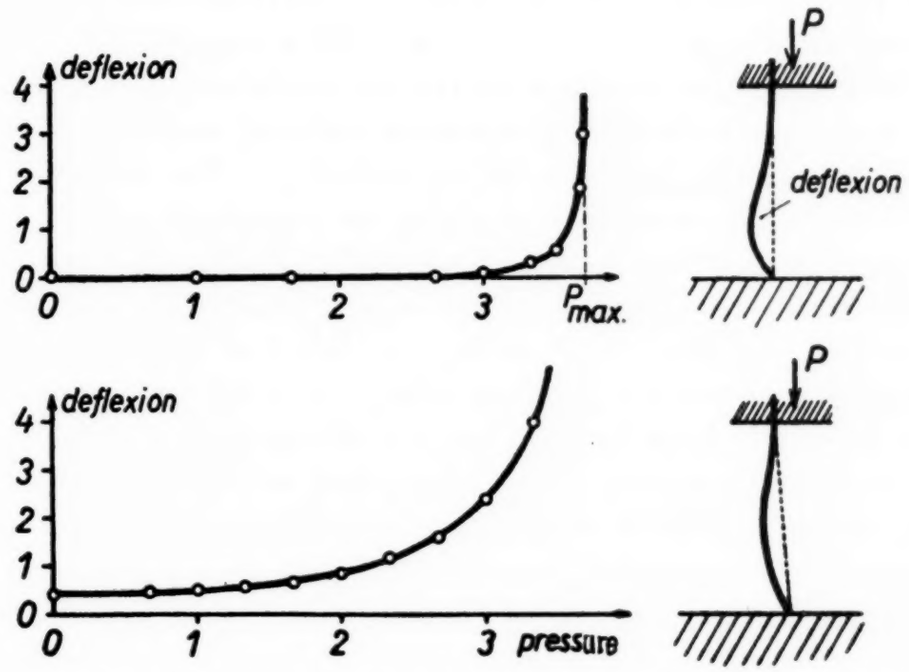

FIG. 1. Reproduction of known maximal pressure by means of the limit of stiffness of the bending of a hair.

vibrate only in its longitudinal axis. From the intensity of the current going through the loud-speaker system, we could determine the vibration amplitude of the hair and could arrange to have this amplitude of vibration in the neighborhood the threshold for stimulation.

von Frey (**8**) has shown, by means of a hair stimulus attached to a tuning fork, that sensations of vibration may be aroused by stimulation only in certain spots of the skin. He has further shown that the pressure spots and those sensitive to vibration stimulation coincide and that they are found near the root of the hair. Hence it seemed to be proved, in

spite of the diverse character of the sensations of pressure and of vibration, that they resulted from excitation from the same nervous mechanism.

If this hypothesis is correct, it follows that the relation between sensitivity for pressure and for vibration must be constant on all the places of the skin surface. It was possible to prove the validity of this statement to a certain degree (**2**) the difference of sensitivity between the finger-tip and the forearm being the same in the case of both modalities. But this parallelism of the two kinds of sensation could not be proved for the pressure points (**4**). It is easy to find points on the forearm particularly on the outer surface which, though of constant sensitivity for pressure, differed more than seven times in amount for vibratory sensitivity. For example, we have often succeeded in regulating the amplitude of vibration of the hair stimulus in such a way that the sensation of pressure becomes completely masked by the sensation of vibration, while only 0.5 mm away from this point of stimulation, no sensation of vibration is felt at all but only the pressure sensation caused by the initial pressure of the hair stimulus. If one succeeds in finding the correct point on the skin for vibration, the sensation of vibration becomes often so strong that it seems as if the whole finger would begin to vibrate. It is also remarkable to note, in this case, that the entire sensation ceases when the hair stimulus is displaced as small a distance as some tenths of a millimeter.

These observations would seem to indicate that there are separate nerve terminals for the sensations of pressure and of vibration. This assertion is also supported by the fact that the smallest distance at which two tactile influences can be segregated from each other in space, is considerably smaller than the two-point limen for vibration. If we set the two points of compasses with such a separation that two effects of pressure are clearly perceived, we then receive from the compass points, vibrating at the rate of about 200 vs., but a single sensation of vibration localized in the middle between the two tactile points. Different observers have succeeded in proving that, on the outer surface of the forearm, the points

for pressure and vibration do not coincide in space, but that the point for vibration is a little more distant from the place of entrance of the hair into the skin, the point for pressure. Both points lay, however, exactly above the position of the root of the hair in the lower layers of the skin. Most of the observers were able to differentiate the two points of sensation in those cases of strongly grown hair. This observation is the more easily ascertained the more flatly the hair penetrates into the skin. Figure 2 shows how the threshold of stimulus

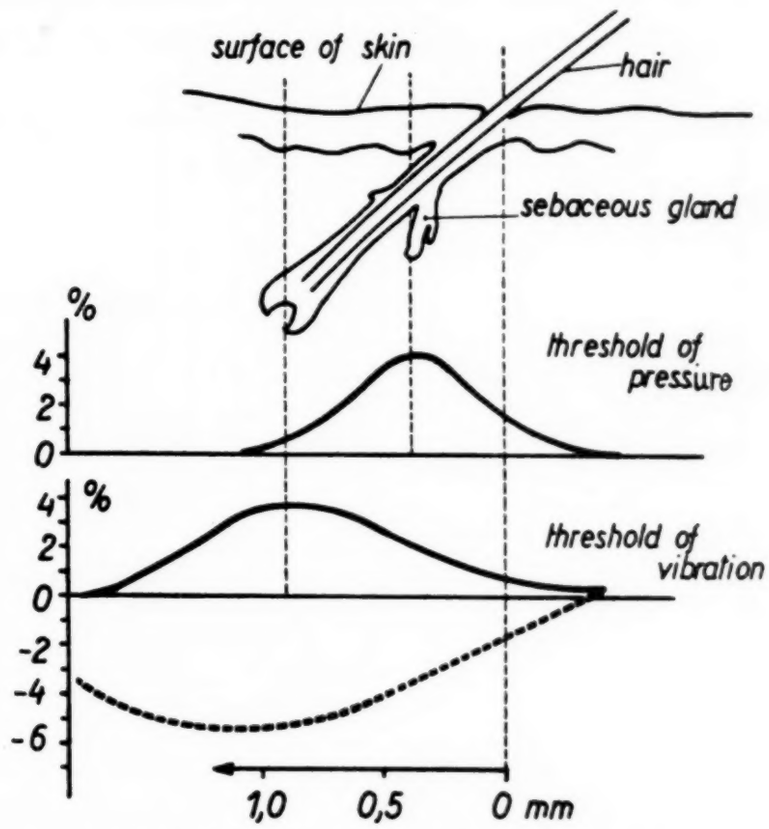

FIG. 2. Segregation in special localization of the sensations of pressure and vibration on the surface of the skin.

changes near the root of the hair, for both sensations of pressure and of vibration, as one proceeds lengthwise over the surface of the skin in the direction of the root of the hair. The ordinates show the relative increase or decrease of the threshold in percent. From these measurements one can easily draw the conclusion that the nerve terminations for the sensations of pressure are to be found directly under the sebaceous gland and that for the sensation of vibration is

found near the hair papilla. The fact that there are also two separate nerve terminals for the two diverse modalities of sensation can also be proved by the following observation. Several observers succeeded, in many cases, to injure the hair by tearing in such a way that the sensation of pressure remained unchanged while, along with injury to the hair papilla, the sensation for vibration was lost. In the bottom part of Fig. 2 is illustrated the curve for the threshold of vibration under normal conditions while the curve with the broken line illustrates the threshold relations after the tearing out of the hair. It can be clearly seen that the maximum, formerly on

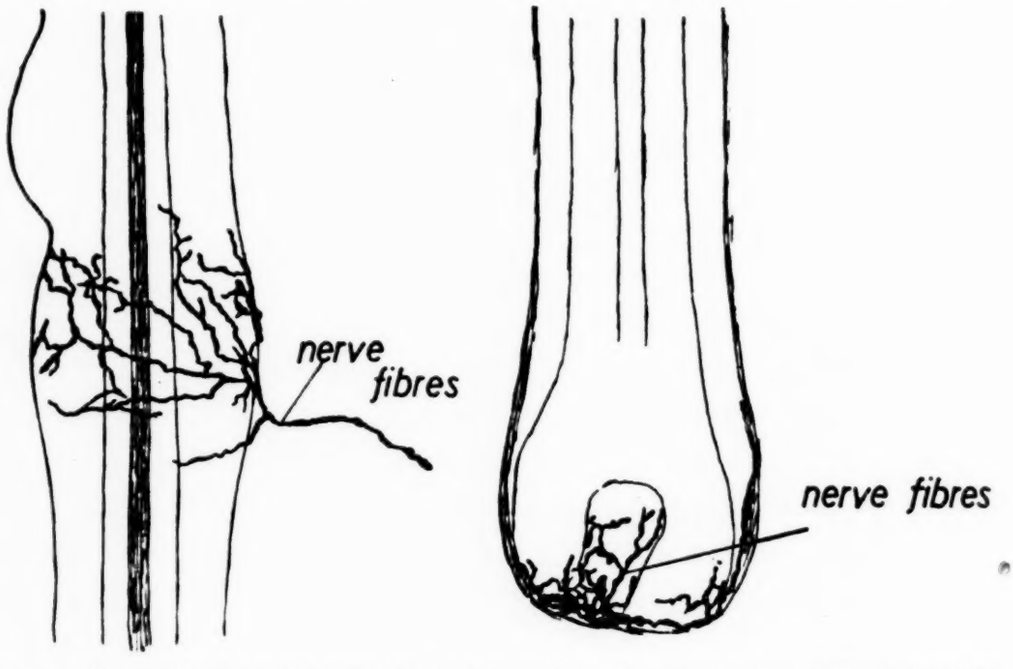

FIG. 3. Nerve fibres on the neck of the hair and on the termination of the hair follicle

the place of the hair papilla has disappeared and that now the vibration sensitivity increases on both sides, attaining at the adjoining hairs once more a maximum.

It is easy to find illustrations showing the nerves responding to pressure stimulation (**3**). They surround circularly the whole hair follicle immediately under the sebaceous gland. The nerve terminals, which are to be found in the papilla, are mentioned in different places (**5**), yet it was possible to find but two illustrations of them (**6**, **7**). This circumstance is due to the fact that these nerve fibres can be stained only with difficulty. In Fig. 3 will be found illustrations of the

two types of nerve fibres of the hair as illustrated by Retzius (**6**). On the left side one can clearly see the circular spreading out of the nerve fibres around the hair follicle, while on the right side are shown the fibres penetrating into the hair papilla. Both figures represent the nerve fibres, but up to the present time it has been impossible to stain the real terminal end organs.

Summary

By means of measurement of great precision for punctiform stimulation of the surface of the skin, it has been possible to localize separately the sensations of pressure and of vibration. The sensation of vibration arises from stimulation of nerve endings in the hair papilla and the sensation of pressure arises from stimulation of nerve endings near the sebaceous gland and, on the surface of the skin, about 0.5 mm distant from the point sensitive to pressure.

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